A Comprehensive Study of Refuse Disposal System in Kanpur

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CERTIFICATE

Certified that the work presented in this Thesis entitled "A Comprehensive Study of Refuse Disposal System in Kanpur" by Shashi Raman Shukla has been carried out under my supervision and it has not been submitted elsewhere for a degree.

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SYNOPSIS

A COMPREHENSIVE STUDY OF REFUSE DISPOSAL SYSTEM IN KANPUR

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It has been observed in the Western Countries that about 80 percent of the total amount incurred on solid waste disposal systems, is spent only on collection and transportation. In India most of the big cities like Calcutta, Bombay, Kanpur etc. are over loaded with solid wastes. No systematic study has been made on solid waste disposal problem in India.

In this study Kanpur city was considered for the refuse disposal problem. A qualitative and quantitative characterization of refuse generated from each ward of the city was carried out. During the study period in 1971-72 the non-combustible matter, combustible matter and moisture content in the city refuse were found to be 40, 34 and 26 percent on an average respectively. The average C/N ratio was found to be 38. The average calorific value of refuse was found to be 1350 Kcal/Kg.

For refuse having such a high C/N ratio composting may not be the most suitable method of disposal. Also as the refuse contains large amounts of nonputrescible matter,

it will be necessary to segregate the putrescible and non-putrescible parts for effective composting. This will add to the cost of the process.

On the basis of the characteristics determined two alternatives for refuse disposal methods were considered viz.,

(a) Landfilling by refuse dumping

(b) Incineration

The present study was to evolve a mathematical model for cost analysis of refuse disposal system and for optimization of such cost taking into consideration the large number of independent variables.

Four different capacities of incinerators viz., 50, 100, 200 and 250 T/day were considered at four suitable sites for incineration. Using the various data the cost of refuse transportation and dumping at two refuse dumping sites and the cost of incineration of refuse for different capacities and at different sites were found out by using the developed mathematical model.

It has been observed that as the capacity of incinerator increases, the cost per tonne of refuse of incineration decreases, though the reduction in incineration cost in going from 200 and 250 T/day capacity is negligible. On the basis of the quantity of refuse generated by various wards, served by an incinerator a 250 T/day capacity incinerator has been suggested on each of the sites except site no. 1.

It has been calculated that incineration on site no. 1 is not economical.

By substituting the different calorific values of refuse viz., 1400, 1200, 1000 Kcal/Kg with various percentage of combustible matter (40, 30 and 20 percent respectively) and at different moisture content the total cost of incinerator, the cost of auxiliary fuel required at steady-state and during start-up of incinerator were analysed. The cost of incineration of refuse with a high calorific value was significantly less. Similarly the cost of auxiliary fuel required at higher moisture content for high calorific values refuse was also less. Only during the start-up of the incinerator the auxiliary fuel cost was substantially high.

It has been observed that the practice of landfilling by refuse dumping costs about Rs 4.5/tonne (average) whereas the average incineration cost is about Rs 9.5/tonne. From this it can be easily seen that the incineration cost is about twice the landfilling cost. However due to increase in haul distances with the expansion of city landfilling might not remain economical method of refuse disposal in future. On the other hand the incineration cost can be reduced by reducing the haul distances, using residue after incineration for land reclamation and utilizing the heat generated during incineration for various purposes.

The results obtained from the mathematical model

developed have been provided discussed.

CHAPTER I

INTRODUCTION

1.1. INCREASING ENVIRONMENTAL POLLUTION AND ITS' SIGNIFICAN

Environmental pollution is the fastest growing pro of our modern technological society. Factors of population expansion, industrial growth, and urbanization have contribut significantly to the accelerated rate of degradation of the environment in metropolitan areas within recent years. Resources which are essential for human being to live-upon as water which we drink, air which we breath and food which eat are getting increasingly polluted and scarce. There are other numerous deleterious effects of the polluted environ which are equally hazardous to the ecology of nature, e.g. effects on wild life, aquatic life and plants etc.

It has been reported by Thring [1] that the slow steady attrition of the quality of life by all kinds of pollution is becoming so serious that, unless we take rapid and radical action to reverse the trend, life will be intol able in the year 2000 in and around all the big cities of the world.

1.2. POLLUTION OF AIR, WATER AND LAND

For a detailed consideration environmental pollu can be divided into three following categories.

1.2.1. Air Pollution

Air pollution is not a recent occurrence. Primitive man too introduced foreign substances in the atmosphere with his fires and other activities. The difference lies in that modern man has accelerated this process of pollution till it has reached the present alarming proportions.

Sources of air pollution can be classified broadly as power and heat generation systems, industrial processes, transportation, and quite paradoxically the abatement processes for solid and liquid pollutants e.g. incineration, anaerobic fermentation etc.

Tinker [2] has placed the annual costs of air pollution in U.S. alone at over rupees 12000 crores ($ 16 billion) from damage to health, material, vegetation and crops. If a means could be found to evaluate human discomfort from illness and aesthetic damages, the total would surely be higher.

1.2.2. Water Pollution

Water is another essential for life available freely in natural environment. It evaporates from lakes, streams, rivers and oceans and then returns in the form of rain, ultimately flowing back to the oceans through rivers. Using rivers as natural sewers, man introduces large amounts of waste products, including toxic chemicals from factories,

into this cycle. Once the ecology of the streams is affected, it may jeopardise not only the food cycle but the nitrogen cycle too. It has been noted in an article [3] that lake Erie in the U.S. is biologically virtually dead. Acidic wastes from surrounding factories have killed every form of life in the lake except sludge worms and a new variety of carp that has adjusted to living off the poisonous environment. River Hudson is fouled. The Rhine has earned the name "Europes' notorious sewer". Darney [4] has mentioned that in the U.S. the average householder's expenditure on water services are now as large as rupees 75 ($ 10) a month, due to the raw water sources being polluted.

1.2.3. Land Pollution

During recent years a new problem of environmental pollution has come to attention and that is land pollution due to solid wastes. The magnitude of solid waste disposal problem is not yet clearly understood even by engineers and scientists and public officials who have to cope with it. Each new technological advance increases the variety of goods that are used. New materials and chemical result in thousands of new pollutants and disposal problems, none of which can be prejudged for their impact on the environment or the economy. It is reported by Small [5] that today there is general experience that solid wastes are a cancer growing on the land, awful in themselves and awful in the way they

further foul the already polluted air and waters near them – a third pollution inextricably interlocked with the two that have been longer experienced as unacceptable environmental hazards. McKinney [6] has mentioned that the population of the U.S. would be doubled by the year 2000. On a shorter term basis, the refuse production in the U.S. is estimated to rise from 152000,000 tonnes per year in 1963 to 264000,000 tonnes per year in 1980. It has been observed by Darney [4] that average householder in the U.S. has to spend rupees 13.2 ($ 1.75) per month for solid waste disposal.

1.3. SIGNIFICANCE OF SOLID WASTES, AESTHETIC, HEALTH AND ECONOMIC

Although most of the deleterious effects of a dirty environment cannot be accurately assessed physiologically, psychologically or economically but still there are some ways and means by which the effects of the polluted environment can be judged. Following are the major aspects by which the adverse effects of polluted environment by solid wastes can be viewed.

1.3.1. Aesthetic

When the transportation of refuse for the disposal is not prompt, it gives rise to severe problems due to accumulation of refuse. The accumulated refuse creates unsightliness and aesthetically it is not desirable for

human beings who live in such environment which is surrounded by the decaying refuse over the land. Some times decaying refuse starts giving malodor which creates nuisance in atmosphere. Refuse dumped on an open ground encourages the stray animals to rummage among the dumped wastes. During rains the water falling on the collected refuse leaches away a considerable part of the organic matter and spreads it all over the surrounding areas. Lighter materials are prone to be carried away by the winds which is also undesirable from the aesthetic viewpoint. In many of the cities of undeveloped countries where the refuse depots are situated near open drains, it is common occurrence that a part of the solid matter finds it's way into these drains resulting often in chocking up of the drains and their content then overflowing on to the roads and other public places, and eventually flowing into rivers and streams to make them unsightly.

1.3.2. Health Hazards

The epidemiological effects of solid wastes are far more deleterious than appears to the common man. Refuse arising out of community activities in itself may not directly give rise to health hazards but fly and rodent breeding in refuse do indirectly contribute to the breakdown of the health of a population. Black and Weaver [7] are perhaps right in saying "..... the prospect of poisoned air and water preoccupied us; in any event, we failed to

recoganize, untill a crisis was upon us in many communities, the degree to which human health everywhere is risked and the human spirit depressed by the contamination and blight of open dumps and noxious emissions from burning refuse in the open or in obsolete overload incinerator.

1.3.3. Economy

The land and property values in a locality very much depend on the state of solid waste removal system in that locality. People do not want to live in the area where refuse is strewn alaround and thus the value of land decreases. Improperly and unscientifically laid refuse dumps and refuse landfills also may result in loss of life and property due to fire hazards, settlement etc.

1.4. THE CURRENT SITUATION IN INDIA

In villages and smaller towns there are practically no organized refuse collection systems and the refuse is dumped onto small heaps along the outskirts of inhabited areas. Rodents, flies and other insects bread in the refuse and stray dogs, cattle and chicken frequent these piles scattering the material far and wide. In large cities of India refuse is normally dumped from each residential unit onto the refuse heaps located nearby from where it is periodically removed manually or by trollys to permanent refuse depots situated aside of the streets. From these

depots refuse is loaded manually onto open garbage trucks or carts and finally unloaded manually on the dumping grounds which may be low lying area, thus employing landfills as a disposal system. Kawata [8] has mentioned that generally the refuse disposal sequence in most of the cities of India follows this pattern:

(a) Collection at the place of origin into small containers or carts, e.g. dust-bins in the homes and municipal carts for street sweepings, (b) transport by basket and carts to street dust-bins or refuse depots, (c) storage at the dust-bins and refuse depots, (d) collection by trucks, trailers, bullock carts or donkeys at periodic intervals, and (e) final disposal or waste reclamation. When the disposal of a dead animal carcass is involved, the carcass is taken directly to the place of disposal and the usual method is disposal by vultures. Where waste reclamation is practised, various by-products are reclaimed and the income is used to defray partially the cost of collection and disposal of the refuse. Compost manure, rags, brickbates, ferrousmetals, hides and bones are the items reclaimed and sold.

Refuse from most of the Indian cities contains quite a high percentage of noncompostible matter such as sand, silt and grit etc. Where refuse contains more amount of kitchen wastes, waste food etc., it can serve as a food material for pigs. Since pigs get food from such refuse, sweepers do not pay much attention in clearing the refuse

from the place where it is dumped initially.

In some of the Indian cities refuse is used for composting which has got resale value. Due to scarcity of the chemical fertilizer people sometimes prefer to use the compost which is cheaper and easily available. In the cities like Calcutta, Bombay, Delhi etc. where the solid waste problem has become very accute, the authorities concerned are giving thoughts on disposal of refuse by incineration, although no large scale incineration has been reported to date.

1.5. CURRENT SITUATION IN ADVANCED CITIES OF WESTERN COUNTRIES

The dimensions of solid waste disposal problem in advanced cities of western countries are much larger than that of Indian cities. It has been reported in a special report in Environmental Science and Technology [9] on solid wastes that the predominant method of refuse disposal in the U.S. is landfill which at present accommodates over 90 percent of the nations' solid waste at an estimated 12,000 individual landfill sites. It has been also reported that municipal wastes in the U.S. have a high calorific value and can easily be burnt, thus much reducing their bulk, but there are only about 300 municipal incinerators in the whole country. Even then, 30 percent of these are inadequately controlled from an air pollution stand-point. Several European countries are

already utilizing the heat released in an incinerator to raise steam, but the U.S. has been very slow to follow suit. One reason, ofcourse, is that it has not had to – there has always been room to spare, at least upto now, to dump the waste on the land.

Composting is practiced in most of the cities of European countries because refuse produced from these cities contains quite a high amount of compostible matter and there is a good resale value of composted refuse. Kupchik [10] has reported that he surveyed 21 composting plants in 10 European countries. According to him all the composting plants are mechanized.

For the collection and transportation of refuse the most modern methods are used in the U.S. and the European countries. On-site storage of refuse is done in metal or plastic garbage cans. Transportation from the source to the point of disposal is done by special refuse trucks which can accommodate large quantity of refuse by the method of compression. Mostly collection and loading of refuse on disposal sites is done by automatic devices. A typical modern automatic device is shown in Fig. 1.1. According to Darnay [4] in the U.S. ninety cents of each dollar spent on solid waste disposal is spent on picking up and transporting wastes to disposal sites. Of the 2100 crores rupees ($ 2.8 billion) spent on collection in 1966, about 80 percent was for labor alone.

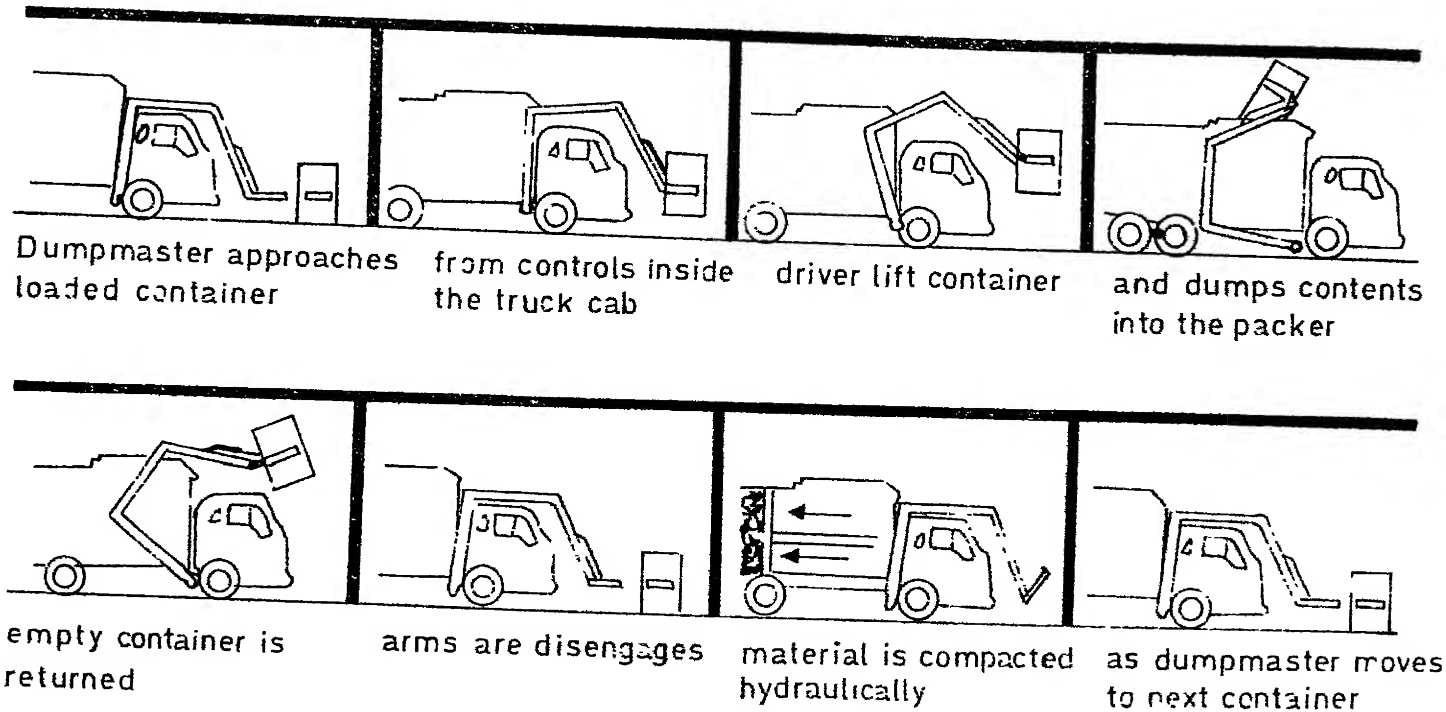


FIG. 1·1 THE DUMPMASTER [23]

1.6. DIFFICULTIES IN ADOPTING IMPROVED METHODS IN INDIA

Following factors may be considered as difficulties in adopting improved methods for refuse disposal system in India.

1.6.1. Unawareness of Authorities

A major obstacle to the solution of solid waste problem is the lack of an awareness on the part of government decision makers that the problem even exists, and it's magnitude.

1.6.2. Technological Factors

The introduction of a new sophistication – both technical and conceptual – into the solid waste field has the potential of revolutionizing one of the least explored aspect of pollution control. That current disposal methods are, to say the least, crude and wasteful in themselves, is being recognized by those in the field, if not by the public at large. Land filling, the single most prevalent method of disposing of municipal refuse demonstrates the prevailing public attitude towards solid waste, "Out of sight, out of mind".

1.6.3. Economic Condition

Economic conditions of any country play an important

role in the control of environmental pollution. Countries like India cannot spend a large sum on solid waste disposal systems, the main reason being that water pollution and air pollution have often to be given priority. But still in some of the large cities, proposals are being framed to introduce modern methods of solid waste collection and disposal systems. Availability of cheap land and labor in many cities also restrict the adoptation of improved methods of refuse disposal.

1.7. CAPITAL INVESTMENT AND COST OF DISPOSAL

For any type of solid waste disposal system the main question which arises is capital investment and the per capita or per tonne cost of disposal. Authorities hesitate to invest a big amount of sum as capital or to incur a considerable cost in disposal of refuse because such disposal systems do not have any return value unless a more scientific and improved method is adopted which can have at least some by-product of resale value such as steam generation in incinerator and mechanical composting for compost.

1.8. METHOD OF CHARGING THE REFUSE DISPOSAL SERVICES

As such, there is no separate charge realised in India for the refuse disposal services. The revenue which is collected by the Corporation or Municipality is generally in the form of house tax. This house tax varies from 15 percent to 25 percent of the property value. This

house tax includes a compulsory water tax of 6.25 percent. The expences on refuse department is borne by the Corporation of the city, out of it's general revenue.

1.9. FUTURE PROSPECTS AND PROBLEMS OF SOLID WASTE DISPOSAL SYSTEM

The problem of solid waste disposal will be much severe than the present one. Because of the fact that the dumping grounds in most of the Indian cities are situated near the present out-skirts of the city but not much thought seems to have been given to the future expansion potential of the city limits. As the city grows the dumping grounds have to be shifted away from the city, which ultimately results in large haulage distance and hence more transportation cost. Also due to rise in living standard, and with socio-logical changes,sweeper always demand more money and facilities which might result in strikes when their demands are not fulfilled.

The future prospects of solid waste disposal system in India seem to be alike water and air pollution control abatments. In the advanced cities of the western countries solid waste problem is ranked at the same level as water and air pollution problems.

Nowadays public is also becoming aware of the hazardous effects of solid waste if it is not properly disposed. Sanitation conciousness is increasing in public

day by day and is in favour of prompt and scientific method of disposal. Keeping all these factors in view adoptation of improved methods of solid waste disposal is necessary for the future.

1.10. OPTIMIZATION OF COST, THE MOST IMPORTANT ASPECT

The effectiveness of any refuse disposal system depends to a considerable extent on the efficiency of collection, transportation and disposal. A major portion of the cost involved is in the transportation of refuse. The transportation cost of refuse mainly depends upon the haulage distance. What-soever may be the refuse disposal process transportation cost is involve in it. A systematic study has to be made to evaluate the transportation and disposal costs for any selected alternative system.

1.11. OBJECTIVE OF THE STUDY

The objective of this study is to evolve a mathematical model for cost analysis of a refuse disposal system and for optimization of such cost taking into consideration the large number of independent variable. The city of Kanpur has been used to test the efficacy of the model, and as an example to demonstrate the applicability of the model developed.

CHAPTER II

LITERATURE REVIEW

2.1. CLASSIFICATION OF SOLID WASTE

The overall solid wastes from a residential community have been called as "refuse" in classical literature. Refuse component materials can be classified in several different ways. One way is to classify according to the activity from which it originated e.g. domestic, institutional, commercial, industrial, street demolition or construction etc. For the selection of a refuse disposal system classification is often done on the basis of organic or inorganic character, combustibility or noncombustibility, putrescibility or nonputrescibility etc. Another important way of classification is based on the kinds of material present e.g. garbage (mainly kitchen wastes), rubbish, ashes, street sweepings, dead animals, abandoned automobile and other equipments, sewage solids and hazardous and special wastes.

The American Public Works Association [11] recommends the following classification, terminology and definitions.

(a) Refuse: All putrescible and nonputrescible solid wastes (except body wastes), including garbage, rubbish, ashes, street cleanings, dead animals, abandoned automobiles and solid wastes from market and industrial

establishments.

(b) Garbage: Putrescible animal and vegetable wastes resulting from the handling, preperation and cooking and consumption of food.

(c) Ashes: The residue from the burning of wood, coal, or other combustible materials.

(d) Rubbish: Non-putrescible solid wastes (excluding ashes), consisting of both combustible and non-combustible wastes such as paper, cardboard, tincans, yard clipping, wood, crockery and similar materials.

(e) Industrial Refuse: Solid waste resulting from industrial processes and manufacturing operations, such as food-processing wastes, boiler house cinder, lumber and metal scraps, etc.

Table 2.1 [12] shows refuse material by kind and composition and also indicates in a general way the source of each kind of refuse.

2.2. CHARACTERIZATION OF REFUSE IN WESTERN COUNTRIES

Hickman [13] has shown the results obtained in a nation-wide survey of U.S., shown in Table 2.2 and 2.3. He states that due to the influence of a large number of variable circumstances, the characteristics of refuse of the surveyed cities are highly variable in nature. The survey showed that the geographical location did not have any significant influence as is often believed to be the case.

Table 2.1

REFUSE MATERIALS BY KIND, COMPOSITION, AND SOURCES [12]

	Kind	Composition	Sources
	Garbage	Wastes from preperation, cooking, and serving of food; market wastes; wastes from handling, storage, and sale of produce.	
	Rubbish	Combustible: paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, wood furniture, bedding, dunnage.	Households, restaurants, institutions, stores, markets.
		Noncombustible: metals, tin cans, metal furniture, dirt, glass, crockery, minerals.	
	Ashes	Residue from fires used for cooking and heating and from on-site incineration.	
	Street Refuse	Sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles.	
Refuse	Dead Animals	Cats, dogs, horses, cows	Streets, side walks, alloys, vacant lots.
	Abandoned vehicles	Unwanted cars and trucks left on public property	
	Industrial wastes	Food processing wastes, boilor house cinders, lumber scraps, metal scraps, shavings	Factories, power plants
	Demolition wastes	Lumber, pipes, bricks, masonary, and other construction materials from razed buildings and other structures	Demolition sites to be used for new buildings, renewal projects, express ways
	Construction wastes	Scrap lumber, pipe, other construction materials	New construction, remodeling
	Special wastes	Hazardous solids and liquids: explosives, pathological wastes, radioactive materials	House-holds, hotels, hospitals institutions, stores, industry
	Sewage Treatment Residue	Solids from coarse screenings, and from grit chambers; septic tank sludge	Sewage treatment plants; septic tanks

TABLE 2.2: PHYSICAL COMPOSITION OF MUNICIPAL SOLID WASTES [13], MAJOR CATEGORIES (% by weight, wet basis)

Location	Paper Products	Metal Products	Glass Products	Food Wastes	Wood Wastes	Plastic, Leather, Rubber, Cloth, Synthetics
New York	40	8	..	10	7	3
New Jersey	51	8	4	10	4	4
Illinois	42	9	6	14	..	..
Ohio	42	7	8	28	3	3
Arizona	43	10	8	22	2	1
California	54	7	2	15	2	2
Kentucky	..	9	6	11	..	..
Tennessee	46	11	11	36	1	5

TABLE 2.3: MUNICIPAL SOLID WASTES [13]. PHYSICAL CHARACTERISTICS DATA (Typical Ranges).

Category	% by weight (wet basis)
Metal Products	8 - 11
Glass Products	8 - 11
Paper Products	40 - 54
Food Wastes	10 - 26
Yard Wastes	3 - 80
Wood Products	3 - 70
Plastic Products	1 - 20
Cloth, Rubber, Leather, Synthetics	1 - 20
Dirt, Ashes, Rocks, & Other Inerts	1 - 50

The two tables included here show the physical composition of refuse. Anon [14] has observed that in general the ash content of refuse is declining in advanced cities of Western countries. The reasons given are the greater use of electricity, gas and oil for heating which lessen the ash content of the refuse. Consumers packaging winds up as increased paper and plastic refuse. Table 2.4 shows the variation in refuse characteristics of the different advanced Western countries. Meissner [15] has reported by referring to the survey of New York city refuse made by Kaiser et al in 1958 that the total weight of refuse from a typical 500 population varied from 327 to 386 kg/day (720 to 850 lbs/day). The moisture content of this refuse was low and ranged only about 10 percent of the total refuse. He has also mentioned that the average heating value of refuse was 3330 Kcal/kg (6000 Btu/lb.). Analysis of typical apartment-house [15] refuse is shown in Table 2.5.

Bloodgood [16] has reported from a study at Purdue University that the percentage composition of the refuse from the campus community was found to be affected by the season, but average figures were as follows: (by dry weight), paper 44.9 percent; garbage 26.4 percent; metal 13.3 percent; glass 13.2 percent; and ashes 2.2 percent. By volume the percentages were paper 74.2; garbage 7.0; metal 13.1; glass 4.8 and ashes 0.9. The bulk density was 105 kg per cubic meter (6.58 pounds per cubic foot) and collection amounted to

TABLE 2.4: A SUMMARY OF INTERNATIONAL REFUSE COMPOSITION (%) [14]

Countries	Ash	Paper	Organic Matter	Metals	Glass	Misc.
1. United States	10	42	22.5	8	6	11.5
2. Canada	5	70	10	5	5	5
3. United Kingdom	30-40	25-30	10-15	5-8	5-8	5-10
4. France (Paris)	24.3	29.6	24	4.2	3.9	14
5. West Germany (West Berlin)	30	18.7	21.2	5.1	9.8	15.2
6. Sweden	0	55	12	6	15	12
7. Spain (Madrid)	22	21	45	3	4	5
8. Switzerland	20	40-50	15-25	5	5	..
9. Netherland (The Hague)	9.1	45.2	14	4.8	4.9	22
10. Norway (Summer)	0	56.6	34.7	3.2	2.1	8.4
11. Norway (Winter)	12.4	24.2	55.7	2.6	5.1	0
12. Israel	1.9	23.9	71.3	1.1	0.9	1.9
13. Belgium (Brussels)	48	20.5	23	2.5	3	3
14. Czechoslovakia (Summer) (Prague)	6	14	39	2	11	28
15. Czechoslovakia (Winter)	65	7	22	1	3	2
16. Finland	..	65	10	5	5	15
17. Poland	10-21	2.7-6.2	35.3-43.8	0.8-0.9	0.8-2.4	...

TABLE 2.5: ANALYSES OF TYPICAL APARTMENT HOUSE REFUSE [15]

Proximate analysis (Percent)

Moisture	10.0
Volatile matter	59.3
Fixed carbon	8.2
Ash and metal	22.5
Total	100.00

0.6 kg (1.32 pounds) per capital per day. Quartly [17] has reported the characteristics data of garbage from San Diego, California as shown below:

Characteristics:	Moisture %	N %	P_2O_5 %	C %	C/N
Raw garbage:	68-74	2.3-2.8	1.2-1.7	46.6-51.8	18.1-22.0

Clarke [18] referring to variations in refuse fuel value from city to city and, in the same city from day to day, assigns such variations to the following causes.

(1) Rainfall affecting the moisture content of refuse

(2) The extent to which coal is used for domestic heating

(3) Influence of certain types of industrial refuse on fuel value

(4) The extent to which parts of the combustible refuse are diverted by salvage, garbage-grinders, hog feeding, household burning and the like

(5) Variations in practice as to the extent of refuse collection service. In some cities, for example, service is given only to residences, thus excluding commercial refuse with its high proportion of combustible solids. In Table 2.6 approximate refuse characteristics involved in its' combustibility are shown.

TABLE 2.6: APPROXIMATE REFUSE CHARACTERISTICS [18]

Class of refuse	Percent Moisture	Percent inert dry solid	Kcal/kg (Btu per lb.)
Wrapped garbage	60-65	20	1415-1610 (2500-2900)
Combustible rubbish	20-30	15-20	2780-3330 (5000-6000)
Garbage and combustible rubbish	30-40	15-20	2220-2780 (4000-5000)
Combustible and noncombustible rubbish	20-30	50-60	1415-1940 (2500-3500)
All classes collected together	25-35	40-50	1665-2220 (3000-4000)

It has been reported by Gorden [19] that in U.K. refuse accumulates at approximately 0.68 to 0.92 kg (1.5 to 2.0 lb.) per person per day. The average percentage by weight of the various item in the refuse are given in Table 2.7.

2.3. CHARACTERIZATION OF REFUSE FROM INDIAN CITIES

The characteristics of refuse from Indian cities vary considerably from city to city. The main factor which affects the composition of refuse is the socio-economic standards in the city. In general refuse from cities of India consists of quite a high percentage of garbage and noncombustible matter. A survey carried out by CPHERI [20] during March-June 1970 revealed that the percapita refuse produced in Calcutta, the largest city in India, was 0.512 kg/day which is comparable to that of Bombay but greater than that for cities like Poona and Nagpur which average at 0.3 kg/day. The Calcutta refuse contains a large proportion (10% by weight) of green coconut-shells. Paper, rags, and glass were found only at the source, most of which were reclaimed enroute to disposal site. The refuse at the disposal site hence contained mainly garbage, broken earthen-ware pieces and ashes. Table 2.8 gives some physico-chemical values at the source and at disposal site for Calcutta and at the source for Poona. Average of 4 U.S. cities is included in the table for comparision. The high percentage of inorganics thus gives a higher density and a lower calorific value.

TABLE 2.7: PERCENTAGE BY WEIGHT OF THE VARIOUS ITEMS IN U.K. REFUSE [19]

Item	% by weight
Dust under 0.795 cm (5/16 in)	36.11
Cinder under 1.905 cm (3/4 in)	16.75
Cinder over 1.905 cm (3/4 in)	12.23
Vegetable matter	3.43
Paper and card-board	12.38
Metal containers - Food	3.14
Metal containers - other	0.60
Other metals	0.91
Textiles	1.27
Bottles and jars	2.84
Broken glass	2.42
Bones	0.29
Combustible refuse	2.08
Noncombustible refuse	5.55
	100%

Density of refuse: 330 kg per cum (20.7 lbs per cuft)

TABLE 2.8 [20]

Item (% by wt)	Calcutta (Ave. of 308 Samples)		Poona	U.S. (1963 ave. of 4 cities)
	Source	Disposal site		
Garbage	45.14	47.25	67.64	22.0
Paper	3.18	0.14	8.74	42.0
Glass	0.379	0.24	0.58	6.0
Rags	3.60	0.28	1.63	0.6
Plastics	0.645	0.54	0.72	1.5
C	19.28	20.31	22.03	28
N	0.564	0.573	0.823	0.33
P	0.591	0.451	0.596	.....
K	0.427	0.479	0.544	.....
Density kg/M^3	470	540	298	250
Calorific value (HCV) in Kcal/kg	1500	......	1700	2728

Table 2.9 gives an approximate average analysis of city refuse as reported by Krishna Rao and Savalappan [21].

The average physical and chemical characteristics of Calcutta city refuse is shown in Table 2.10 and 2.11 respectively reported by Bhide et al [22]. Tables also show the samples collected from different areas of the city.

2.4. COLLECTION, HANDLING AND TRANSPORTATION OF REFUSE IN MODERN COMMUNITIES

There are three basic operatives which govern the selection of further handling and disposal system of refuse and the cost of the overall service

(1) Collection Method

(2) Collection Frequency

(3) Mode of Transportation to disposal site

2.4.1. Collection Method

One of the most important factors which determine the cost of refuse collection at the source is the length of carry, which is the distance the collector must walk from the transport vehicle to the refuse bin and back. As mentioned by Flintoff and Millard [23], in cities of the western countries some local contrive to reduce length of carry to a minimum by requiring householders to perform part of the refuse collection themselves, either by placing the bin on the footway sometime before collection, or by carrying the

TABLE 2.9: APPROXIMATE AVERAGE ANALYSIS OF CITY REFUSE [21]

Item	Content, %
Hay and straw	17.68
Paper and rags	6.46
Vegetable wet matter	5.73
Vegetable dry matter	53.60
Tin and metal	0.16
Dust and ash	13.90
Glass and crockery	0.52
Offal, fish etc.	2.05

TABLE 2.10: SOME AVERAGE PHYSICAL CHARACTERISTICS [22]

S.No.	Type of locality	Leaves	Garbage	Hay & straw	Paper	Rags	Polythene & plastic	Glass
1.	Residential areas							
	a) Low income group	10.18	12.85	6.40	3.82	1.20	0.87	0.31
	b) Middle income group	11.26	16.67	5.46	3.10	3.48	0.50	0.50
	c) High income group	12.085	18.87	5.52	4.01	3.61	0.80	0.63
	d) Slum area	10.04	16.12	7.69	2.91	4.61	0.49	0.12
2.	Commercial area	13.76	16.11	7.57	3.64	3.56	0.50	0.40
3.	Market area	15.10	19.36	6.21	2.52	3.15	1.01	0.60
4.	Industrial area	19.22	12.34	5.67	2.20	4.57	0.59	0.08

Note: All values are given in percentage.

TABLE 2.11: AVERAGE CHEMICAL CHARACTERISTICS [22]

S.No.	Type of locality	Moisture %	pH	N %	P as P_2O_5 %	K as K_2O %	Organic Matter %	C %	C/N ratio
1.	Residential areas								
	a) Low income group	42.16	7.325	0.5984	0.5102	0.3546	34.03	18.90	31.58
	b) Middle income group	41.559	7.22	0.524	0.567	0.359	34.89	19.39	37.00
	c) High income group	40.521	7.331	0.5186	0.5524	0.3959	35.07	19.45	37.50
	d) Slum area	45.021	7.42	0.552	0.629	0.415	31.55	17.53	31.41
2.	Commercial area	40.213	7.21	0.427	0.617	0.312	39.04	21.69	50.80
3.	Market area	43.65	0.936	0.575	0.5876	0.428	39.26	21.82	42.12
4.	Industrial area	51.35	7.16	0.675	0.575	0.675	40.14	22.30	32.94

empty refuse bin back after emptying. Other authorities, mostly small ones, limit their service to emptying bins placed at the kerb side. It has also been mentioned that the saving in labour cost by using the kerb side collection as compared with a complete service, can be between 30 percent and 45 percent depending on the length of carry.

Two common methods of refuse collection have been described by Flintoff and Millard [23] as follows.

2.4.1.1. Collection and return bin system

The most usual method of collection is that in which the refuse collector removes the bin from its normal stance at the side or rear of the premises, empties the contents into the vehicle and returns it to its stance. In some cases refuse teams are so organized that one or two men work ahead of the vehicle bringing out the full bins and leaving them on the foot-way to be emptied and returned by the other collectors.

2.4.1.2. Exchange bin system

Some local authorities in western countries have experimented with an exchange bin system, whereby the collectors start with one empty bin and leave it in place of the first full bin removed for emptying. The latter when empty is left at the second house and so on. Such a system works only when bins are supplied and owned by council.

Efficiency of collection depends on the size, shape, weight and the capacity of containers. The capacity of containers in western countries ranges from .068 m^3 to 0.113 m^3 (15 to 25 gallons) each with corresponding weights, when empty, of 9.1 to 12.7 kg (20 to 28 lb.) each. In order to keep pace with the progressively bulkier refuse, containers are becoming larger, although their gross weight is not necessarily greater. An interesting container system has been described by Rogus [24] in western Europe now used on a modest scale in several European communities. This is a mobile or fixed metal stand or a bracket having a top hinged cover and a special ring from which a disposal sack is hung. The two ply-bag, made of wet strength reinforced paper, is quite tear-proof and moisture resistant. The favored size, holding about 0.071 m^3 (2.5 cuft) and capable of supporting upto 32 kg (70 lb.) of combined refuse, weighs about 0.152 Kg. Removal of the loaded bag and its replacement with a new bag is simple and quick.

In a report in Public Works Journal [25] it is stated that use of disposable paper bags to replace garbage cans as outside refuse containers has been officially adopted by Riverdale, Md., a Washington suburb with a population of about 6000. Each resident was furnished with a supply of bags, each of which holds about twice as much as the average garbage can, and a metal stand-type holder. The holder which is placed in standing position any where out side the house

or in the garage, has a rubber-ringed lid and encompassing metal arm to which the bag is affixed by a simple clamping device. It has been mentioned by Sanborn [26] that until early 1964, Junction city, Kansas, had a major problem in garbage removal, a problem common to many American cities. The community was plagued by unsanitary and unsightly garbage and trash metal containers. Realizing the problem a new system was employed having weather-proof, heavy duty disposable paper bags hung from metal holders of various designs to meet particular conditions. The bags were manufactured from stretchable kraft paper, treated with resins to make it weather-proof and leak-resistant.

It has been reported by Mendoza [27] that the refuse collection in San Diego, California, combines advanced operating procedure and reasonable regulatory provisions, generally approved by citizenry. This combination permits a highly economical refuse collection system in this city of more than 600,000 inhabitants. One of the most important aspect is that citizens are asked to place their refuse out for collection on public property. This obviously reduces the amount of time and labour required for collection service. As another aid in reducing refuse collection costs, the City Council some years ago approved an ordinance establishing specifications for containers for refuse. This ordinance requires that

(a) Container shall be made of either metal or water-proof wood, or water-proof fibre composition, excepts for rectangular wooden container as described below.

(b) Containers shall be in the form of truncated cones or cylinders, preferably the former.

(c) Capacity of container shall not be exceed .2 m^3 (45 gallons).

(d) The maximum weight of empty container shall not exceed 11.35 kg (25 lbs.).

(e) The maximum weight of loaded containers shall not exceed 36.3 kg (80 lbs.).

(f) The interior surface of the container shall be smooth and they shall have no interior projection which interfere with the emptying of the containers.

(g) The top diameter of the container shall in no case be less than any diameter of the container below the top.

(h) Rectangular wooden containers not exceeding 0.071 m^3 (2.5 cuft) in capacity and/or metal wash tubs may also be used as rubbish container.

2.4.2. Collection Frequency

The following factors have to be considered in connection with frequency of refuse collection.

(a) Refuse has a putrescible content, which if left for more than a few days will become offensive, particularly in summer. The householder will thus welcome the most

frequent collection possible.

(b) Flies are attracted to the contents of refuse bins. In order to prevent fly infestation, therefore, all house refuse should be removed at least once weekly and where the refuse is of a predominantly putrescible nature, a twice weekly collection is the minimum that is provided in western countries.

In the cities of the western countries a fortnightly collection fails to satisfy the minimum demands of hygeine as mentioned by Flintoff and Millard [23]. Bins will be overflowing and may be heavy to lift. Nothing less than a weekly collection is provided for household refuse. More frequent collection is necessary from hotels, restaurants, cafes, food shops, and large buildings in multiple occupation, and probably blocks of flats, too.

A Survey Report in Public Works Journal [28] made on Berger County N.J. which included 70 municipalities, is stated that in 95 percent of the communities refuse is collected in residential areas atleast twice a week during summer. In a few places there is one less collection in winter. Collections are generally more frequent in commercial and residentials sections. Point of pickup varies from place to place - the curb in some areas, the backyard in others; placement of the empty cans also varies.

According to a survey carried out by Rogus [29] in Western Europe, inspite of lesser per capita output of

refuse, the frequencies of collection in Europe seem to be greater than U.S.. As shown in Table 2.12 frequencies are mostly two and three times per week and upto seven times per week in a few of the larger cities. Table 2.13 represents some comparative data on refuse containers.

2.4.3. Mode of Transportation to disposal site

The adaptability of refuse collection and transportation equipment to individual local situations is of the greatest importance if the service rendered is to be sanitary, inoffensive, and effective, and at the same time as economical as possible. Numerous features of a collection service are taken into account in selecting equipment of the transportation of refuse. The class of refuse collected, collection frequency, collection method, length of haul, width and condition of streets and alleys, and a city's size, financial position and labor rates are important and determine the essential characteristics of the vehicles best suited.

The basic determinations to be made include the size and capacity of vehicles, loading height, speed of loading, degree of compaction, retention of compaction, vertical clearance of loading aperture, appearance, unloading devices, whether it is easily cleanable, speed of travel, watertightness, and numerous other features to design or construction.

TABLE 2.12: COLLECTION CHARACTERISTICS [29]
(Approximation based on total
population served)

Country	Frequency of collection	Seperation		Point of Pick-up		Collection	
		Percent Seperate	Percent Combined	Percent Curb or Bldg-line	Percent Backyard or Bldg.	Percent Municipal	Percent Contracto:
1. U.S.A.	10 percent: 3 to 6 47 percent: 2 43 percent: 1	50	50	50	50	90	10
2. England	1 to 5	90	10	10	90	95	5
3. France	10 percent: 7 40 percent: 6 50 percent: 3	5	95	100	..	100	..
. Germany	100 percent: 2	..	100	...	100	100	..
. Scotland	50 percent: 1 50 percent: 2	100	...	15	85	100	..
. Sweden	50 percent: 1 50 percent: 2	...	100	...	100	15	85

TABLE 2.13: REFUSE CONTAINERS [29]

Country	Size in M^3			Ownership		Mainten- ance		Use of Std. Size Fully covered containers	Empty wt in Kg	
	Range	Median	Hermative Collection	Percent Municipal	Percent Private	Percent Municipal	Percent Private	Percent	Range	Mean
1. U.S.A.	.045-.228	0.114	...	5	95	5	95	50	3.2-11.3	7.
2. England	.045-.114	.09	...	20	80	20	80	80	...	11.
3. France	.023-.090	.068	0.114	10	90	10	90	100	...	6.
4. Germany	.09-.135	0.114	0.135	80	20	80	20	100	11.3-22.6	22.
5. Scotland	.09-.135	.09	...	..	100	10	90	100	11.3-22.6	11.
6. Sweden	.09-.3	0.16	0.16	50	50	50	50	100	11.3-27.2	25

In western countries most modern methods of transportation of refuse are being practiced. A survey report in Public Works Journal [30] lists and describes the refuse collection methods and equipment used in 35 typical cities, with the population ranging from 134,000 to 510,000 of the U.S.. A study was made on the saving in cost by using Packer-Type trucks. Personnel requirements were reduced from four men to two men per collection unit by the use of packer-type trucks in Santa Monica, California. It has also been reported that cost figures on maintenance and operation for Waterloo, Iowa, indicate that the saving through the use of packer trucks amount to about Rs. 56.2 ($ 7.50) per day for each collection unit and crew. A crew consists of a driver and two loaders; pickups are from alleys and in the rear of houses. In Boston, Mass, estimated daily saving in cost for packer-type trucks is Rs. 75 ($ 10) as compared to open trucks; and in addition only three men per truck are needed as compared to four on open units.

It has been mentioned by Robertson [31] that by using a dumper type of truck for long hauls the efficiency of refuse collection has increased in saving considerable time on the routes. Because as soon as one truck is loaded it is taken to the disposal area by the driver and unloaded. The remaining crew members then start loading the other truck.

Neilson [32] has reported that the city of Winston-Salem in U.S. now uses the following equipment for the collection

of house-hold refuse: 13 Scow type dump trucks; 19 load packer-type trucks; and 3 Dempster-Dumpster truck unit which service approximately 100 Dempster-Dumpster boxes. These packer trucks are of mechanical type. It has been found that this type of equipment gives a very satisfactory service and that it is cheap to maintain and operate.

2.5. COST ANALYSIS OF REFUSE HANDLING AND DISPOSAL

Various studies have been carried out in Western countries on the cost analysis of refuse handling and its disposal.

Quon et al [33] have shown a detailed, computerized analysis of a municipal refuse collection system. The main objective of the computation with the simulation program developed by the researchers was to point out the relationship of several significant variables involved in the functioning of a refuse collection system. The simulation method of analysis allows an economical means of investigating changes in the operation of refuse collection systems without resorting to actual field trials. The parameters considered in the simulation of the daily refuse collection are:

1. Number of houses from which refuse is to be removed.
2. Frequency of trips to the disposal site.
3. Overall collection, pickup, and haul efficiencies.
4. Truck capacity.
5. House density in a locality.

6. Average and variability in the quantities of refuse produced daily.
7. Haul distance.
8. Frequency of services.
9. Number of unloading docks at the disposal site.

Another computer model developed by Quon et al [34] for simulation analysis to evaluate the dynamic characteristics of refuse collection crews employed on a constant-length workday basis. The constant length workday simulation program was used to evaluate under different operational policies, the overall performance of the collection crews, and the quality and unit costs of the service provided to the service area (dollar/ton, dollars/service/week, percentage on time collection). Policies relating to the over/time, the use of relay drives for hauling the last load of the day, the average quantity of refuse assigned per crew, and assigned total length of workday were evaluated for a hypothetical service area. Unit cost expressed as dollars per service per week was found preferable to unit cost expressed as dollar per ton in assessing the cost of refuse collection.

A digital computer simulation model was prepared by Truitt et al [35] for complex urban mixed-refuse collection systems. The model makes it possible to calculate the number of daily truck routes in each subarea as a function of household density, collection frequency, and collection truck haul distance. With the use of this model, costs of

alternate location for final disposal sites and transfer stations sites are investigated and compared. The model is structured so that local field performance data, truck costs, labor costs etc. can easily be included in evaluating the desirability of proposed policy changes. The simulation model was claimed to be sufficiently general for use in any urban situation. Owen [36] has reported a newly developed family of proprietary computer programs for route analysis, and simulation of refuse handling. Application of the program produces an area-wide plan of individually balanced collection routes on a street-by-street, house-to-house basis. Route lengths are formulated in accordance with management policies establishing workday length which are specified by the users. Each route is optimal with respect to time in terms of specified garage and disposal point locations.

2.5.1. Cost Analysis of Refuse Handling and Disposal in India

There is, no systematic study of cost analysis has been made to evaluate the cost of refuse handling and disposal in India. However, some of the cost data are given here, which were analysed in few of the cities.

As mentioned in a report [20] the cost of refuse haulage was Rs. 1.15 per km-tonne, where as cost of refuse dumping, spreading and partial compacting at a representative

site (Nawapara) was found to be Rs. 2.50 per tonne. The cost of collection and disposal of the refuse in Kanpur city as worked out in Appendix I is Rs. 2.50 per capita per annum. The corresponding figure for the city of Bombay is given as Rs. 9.20 per capita per annum [37]. The probable reasons for the high rate in the latter case may be due to higher per capita quantity of refuse, higher cost of labor and the longer haulage distances.

2.6. REFUSE DISPOSAL

The principal methods of refuse disposal, currently in use over the World, include

(a) Land reclamation by controlled dumping of unseparated or fractionated refuse.

(b) Reclamation of metal, rags, paper etc.

(c) Separation and hog feeding of garbage fractions.

(d) Separation and mushroom cultivation on garbage fraction.

(e) Composting either directly or after seperation of noncompostables.

(f) Incineration either directly or after separation.

(g) Grinding and adding to sewage.

The antithesis of a proper disposal system is the dumping of crude refuse in uncontrolled conditions. Such dumps turn into feeding and breeding grounds for flies and rats and are a nuisance from aesthetic and fire hazard points of view.

The practice of barging refuse out to sea is also prevalent in some of the countries. It is unhygenic because the floatables in the refuse, which are significant in quantity, are likely to cause pollution of beaches.

The alternative disposal methods listed above are suitable for specific types of refuse under specific conditions as shown in Table 2.14, and are briefly discussed in following sections.

2.6.1. Land Reclamation by Controlled Dumping of Unseparated or Fractionated Refuse

The practice of urban land reclamation by dumping of refuse varies greatly from community to community. The simplest form is an uncontrolled open dump in which thick masses of the waste are allowed to accumulate and eventually be covered with earth. In controlled filling, the refuse is dumped in layers from 0.3 m to 1.5 m thick and compacted. As mentioned by Sowers [38] in some cases the wastes may be partially segregated during dumping by size or composition. In most controlled fillings, there is an attempt to compact the waste using the construction equipment at hand, such as bulldozers and front-end loaders. Experience indicates that the volume can be reduced to one-half or even one-fourth of the as-delivered volume by proper compaction. This means that densities are increased to about 292 Kg to 584 Kg per M^3 (800 to 1600 lbs per cuyd). Finally the fill is covered with

TABLE 2.14: COMMON PRACTICES FOR SEPARATION OF REFUSE FOR VARIOUS DISPOSAL METHODS' [12]

Disposal Method	Refuse Suitable for Method	Refuse Unsuitable for Method[1]	Where Separated
Sanitary land fills	Mixed	Tree trunks, stumps, hazardous refuse; offal	Disposal site
Central incineration	Mixed	Large objects that clog hoppers; large metal pieces; heavy wire; hazardous materials, heavy timber; tree trunks	Combustible at sources; sometime all refuses collected together
Central grinding	Garbage, some paper	Inert material that cannot be reduced at sewage treatment plant or cannot be carried in sewers; cans, metals, glass, earth	Source; wrapping usually prohibited
Feeding food wastes to swine	Garbage	Paper, citrus rinds; cans; glass	Source; wrapping prohibited
Composting	Organic desirable; inorganic acceptable	Large ungrindable objects - tires, metals; logs	Source or plant
Salvage & reclamation	Materials with resale value	Varies with market for salvage	Source or disposal facility
Open dumping	Some non-putrescibles	Putrescibles	Source or dump
Open burning[2]	Tree branches, trunks, combustible rubbish	Garbage; other putrescibles	Source

1. Complete or almost complete separation desirable in all methods.
2. Not a recommended disposal method; acceptable only under special circumstances.

soin to minimize odors, and rat and insect nuisances. Generally a 15 cm earth cover is placed on each segment of the fill at the close of each day. Therefore, a sanitary landfill consists of wastes in large cells or blocks, compartmentalized or encapsulated with thin membranes of soil. These cells may be compartmentalized in thin strata over broad areas, in relatively long deep trenches, or in wedges on slopes. A final cover of 0.3 m to 0.6 m of soil is placed over the fill area to level the surface and present a neat surface.

2.6.1.1. Sanitary landfill in western countries

Sower [38] has reported according to the studies carried out by the University of California that from 0.617 to 1.85 hectare-m (5 to 15 acre-ft) per year are required for 10,000 population of total waste, excluding industrial waste, in U.S.. In a report by the Committee on Sanitary Engineering Research [39] it has been observed that the sanitary landfill is the most common method of solid waste disposal for communities in the U.S.. In 1946 there were less than 100 communities using this method while today there are between 1,000 and 1,500 communities operating landfills. Weststrate [40] has mentioned that in Netherlands about 50 percent of the municipal refuse is disposed through landfills, about 25 percent is incinerated while the remaining 25 percent is processed into compost manure.

The landfill site location directly affects the

total refuse collection and disposal cost. If the disposal area is remotely situated, the cost of hauling may be high and the total cost unreasonable. It has been mentioned by Salvato [41], that the normal economical hauling distance to a refuse disposal site is 16 to 23 km (10 to 15 miles), depending on volume of refuse and other factors. Actually, hauling time is more important than the hauling distance and a dumping site could be even 48 to 64 km (30 to 40 miles) away if a transfer station is used. In such cases the collection vehicles deliver to a relatively nearby transfer station and larger capacity vehicles pickup the refuse there and haul it to the disposal site. Another important consideration mentioned by Salvato [41] for the dumping site selection is it's accessibility. According to him a disposal area should be located near major highways in order to facilitate the use of existing arterial roads, and reducing the hauling time to the disposal area.

As reported by Jacobson [42], at the Cedar Hills sites of the elaborate refuse disposal system of King County, Washington, a Koehring Scooper lifts large trailor containers for dumping at the disposal point. The unit can lift upto 11400 Kg (25000 lbs) with a reach of 6.55 m (21.5 ft). A proposed disposal system would use a machine operating in a trench to compact the refuse to a tenth of its original loose volume. A bulldozer would follow the operation and place earth cover over the compacted refuse in the trench.

The problem of utilizing sanitary landfill for building developments is rapidly becoming more important. This is the result of increased demand for areas for sanitary landfilling and the subsequent demand for usable property for urban development. The sanitary landfill, however, is inherently a poor supporting medium because it is weak, it settles substantially, it produces hazardous or obnoxious gases, and is extremely difficult to work on. Along with the settlement of landfill Sower [38] has mentioned other effects of landfill as (1) corrosion and deterioration of embedded structures and (2) gas production. Adverse effects of these factors are as follows:

(1) Corrosion and Deterioration of Embedded Structures: Because the wastes in the sanitary landfill are active chemically and biologically, they can produce corrosion and deterioration of structural materials. Some of the products of organic decomposition are highly corrosive, such as organic acids and hydrogen sulfide gas in the presence of moisture. Materials such as cinders react with water to form weak acids which attack metal and can cause deterioration of concrete. Some industrial wastes are detrimental to piles and structural materials.

(2) Gas Production: Gases are generated by organic decomposition and, in rare cases, by chemical reaction within the fill. The principal gas formed by biological decomposition is methane, although, in some cases,

hydrogen sulfide is produced in the early stages of decay. Because of the porous nature of the fill, gas will accumulate within it and slowly escape through soil cover. There are usually numerous pockets and openings in and around structure where the gas may accumulate and present a serious explosion hazard. Gas accumulation in the soil can have a poisoning effect on landscape vegetation. In fact, stunted vegetation can be an indication of gas release. Finally, gas in a fill can present a health hazard. In a report published by State Water Quality Control Board, State of California [43], it has been mentioned that to-date, the only gas of decomposition found in significant quantities in the soil surrounding the fill has been carbon dioxide. Methane was found upto 3.5 percent at 13 m (40 ft) depth from top surface of fill. The maximum concentration of CO_2 was found after 17 day of the fill. An estimate of the velocity of CO_2 movement in soil was made showing 0.3 m (1 ft) per day for horizontal velocity and 0.24 m (0.8 ft) per day for vertical velocity. The porosity of soil was determined to be 20 percent; that of the refuse, 75 percent.

2.6.1.2. Landfill practice in India

In most of the large cities in India landfill is being adopted as a refuse disposal system. In Calcutta,

the largest city in India, refuse is being disposed of by uncontrolled dumping at a number of sites.

Sanitary landfilling costs are with proper mechanical equipment such as bulldozers, scrapers, etc. and when operated with proper schedules and precautions. The benefit lies in avoiding depreciation of value of surrounding lands and in resale value of reclaimed land. Many Indian cities have been utilizing this crude method and reclaiming useful land for future development of the city for quite some time. Some Indian cities such as Bombay and Calcutta have also modified these methods to some extent to make them more efficient. However, it can be said that still there is lot of scope for improvement.

2.6.2. Reclamation of Metal, Rags, Paper etc. From Refuse

The amount of refuse ending up at the community refuse disposal facility is always somewhat less than the total amount produced in the community, the difference depending largely on the thriftiness of the citizens, general economic conditions, the efficiency and extent of the service and the amount of on-the-premises disposal practice. The main factor which affects the lessening of the amount of refuse produced is the salvaged material which is sorted out before the disposal or some times on the disposal site. The amount of material salvaged from household or commercial refuse is closely related to the market value of the by

product.

It has been found by Russel [44] that in 1966, an estimated 9,842,000 tonne (10,000,000 tons) of paperstock (waste paper) were recycled and became raw material for new products in U.S.. Anon [45] has also mentioned that tin cans are salvaged from four sanitary landfill operations by the Los Angeles By-Products Company of California. From 197 to 345 tonne (200 to 350 tons) of tin are recovered at each of the four sites. Copper also is salvaged from the cans. The revenue is as much as several hundred dollars per site per month.

2.6.2.1. Salvage and reclamation in India

In India, many of the constituents found in garbage are to be reclaimed by the sweepers themselves. Even when the material is loaded in the trucks it has been observed that paper, tins, rags, etc., are all recovered by them and are normally found to be kept inside the trucks itself. The net result is that the truck is never filled up completely and for storing this material a large amount of space is kept by the scavengers who go on reclaiming this material while the truck moves from one point to the next. When the material reaches the dumping ground, further reclamation of paper, tins, and rags occur at the dumping ground itself. During these operation it has been seen that most of the material gets scattered all around leading to very insanitary conditions. Normally these scavengers recover

paper on the first priority basis as it has been observed to have good market value. Normally the hard-board manufacturers purchase this paper and use it as raw material for the manufacture of their product. Tins and rags are also recovered by these people and sold as raw material in surrounding market. It has also been observed that some of these scavengers recover unburnt coal which they sell again in the slum areas of the city.

2.6.3. Separation and Hog Feeding of Garbage Fraction

Garbage can be disposed of by feeding it to hogs. It is collected separately, the unedible refuse being separated from it. In colonial times the problem of garbage disposal in large cities was "solved" by turning pigs loose in the streets to serve as scavengers. In view of today's sanitary practices, such a system seems remote, indeed. However, in small communities a pig or two is still frequently the garbage disposal plant for a family. Traditionally, farmers have kept a few hogs that were "slopped" after meal-time with the left-over from the table, trimmings from the preperation of food, and other edibles. Into this melange were sometimes thrown a few handful of grains.

It has been mentioned in a report in Public Works Journal [46] that there is reason to believe that feeding raw municipal garbage to hogs is a cause of trickinosis in humans and animals and vesicular exanthema in animals and

the United States Interstate Quarantine Regulations stipulates that no garbage may be shipped interstate for hog feeding unless first cooked at 100°C for 30 minutes. Almost all states now have laws or regulations requiring proper heat treatment of garbage before feeding it to livestock. An undisputed objection to hog feeding is that feeding lots nearly always give off vile odors, attract flies and rats and are highly unsanitary. Clayton Manufacturing Co. U.S.A. has developed a garbage cooker, for hog feeding.

2.6.3.1. Separation and hog feeding garbage fraction in India

In India, as such, separation and hog feeding garbage fraction is not practiced. However, hog owners allow hogs to rummage with the garbage heaps and thus hogs get edible matter from the garbage. Sometimes, the kitchen waste is separately collected and fed to the hogs. There is no proper treatment is given to the garbage for hog feeding in India as it is being practiced in Western countries.

2.6.4. Separation and Mushroom Cultivation on Garbage Fraction

The practice of mushroom cultivation on garbage fraction is adopted only in Western countries. Mushrooms grow on dead organic matter. In most of the cities in Western countries where the garbage grinders are used in houses or on large scale grinding of garbage by authority,

best suitable and edible species of mushrooms which can be cultivated in India. It has been reported by Budharaja [49] that the production and supply of spawn of various species of mushrooms may become a limiting factor in the expansion stages of the mushroom development program. At present, the Institute of Mushroom Research, Solan, H.P. the Agricultural Department of Jammu and Kashmir and the I.A.R.I., New Delhi along with some other laboratories are producing spawn of different species to meet their local area requirements. One bottle (1/2 liter capacity) of green spawn of white mushrooms is selling roughly Rs. 3.00 per bottle at some of these laboratories.

2.6.5. Composting, Either Directly or After Separation of Noncompostables

Composting is the biochemical degradation of organic materials to a sanitary, nuisance-free, humus-like material. Modern scientific composting has been described as a rapid but partial decomposition of moist, solid, organic matter by the use of aerobic microorganisms under controlled conditions.

There are two general types of biological decomposition: aerobic and anaerobic. Aerobic (with oxygen) decomposition is efficient and rapid, resulting in the oxidation of organic matter primarily to minerals, humus, carbon dioxide and water. The aerobic process if properly

carried out, does not produce foul odors; it is the one employed in most modern scientific composting.

Anaerobic (without oxygen) decomposition is slower and less efficient resulting in the reduction of organic matter primarily to minerals, humus, methane and carbon dioxide. This process is similar to the digestion of sludge in sewage treatment and if it is not properly controlled causes offensive odors by release of sulfides and mercaptans.

There are a number of ways in which compost is manufactured using refuse. Broadly they are classified under two general groups: non-mechanical or manual method and mechanical method. In mechanical plants, certain operations are done using machines, and attempts are made to reduce the time element and area required.

The primary purpose of a municipal refuse composting plant is to treat solid wastes. Therefore, if refuse is collected together, provision is made at the plant to dispose of components that cannot be composted such as metals, tyres, and glass etc. It has been mentioned in Municipal Refuse Disposal [12] that the great variety of refuse material that has been composted indicates that the raw material are not greatly restricted. For example, materials with carbon to nitrogen ratios (C/N) varying from 20 to 78 were successfully composted at the University of California. While it is desirable to keep C/N range in raw

materials from 30 to 40, it is not essential. Some what longer composting time is required with a high C/N ratio than a low one. The desired end C/N is about 28 to 31. Mixed refuse (garbage and rubbish) compost better than separate garbage or rubbish. Garbage is often too wet; rubbish has two high a C/N ratio. The optimum mixture for composting is a well blended mixture of refuse and partially dewatered raw sewage solids plus suitable organic industrial wastes.

2.6.5.1. Composting in western countries

Extensive studies on composting have been carried-out by Wiley and Spillane [50] in U.S. by using windrows and bins. It has been observed that though the grossly sorted refuse used at Chandler contained excessive amounts of ash (from glass, metals, ceramics, etc.) and paper, good decomposition was attained in both windrows and aeration bins. More complete sorting for salvage and discard would greatly improve the quality of compost. Use of windrows was recommended as it appears to be more practical for plant installation. Similar studies have been made in Japan by Kaibuchi [51] on the composting of refuse mixed with night soil. The objective of this study program was to find the maximum quantity of night soil that can be disposed of by composting a mixture of refuse and night soil. Most of the work has been carried out on mechanical composting plants. It was

observed that the satisfactory results were only found when the moisture content of the mixture was 60% or less.

Some of the details of mechanical composting plant is given in a report of Public Works Journal [52]. In the report it has been mentioned that a composting plant constructed at Renton, by Dundarton County Council, to handle 25 to 27 tonne of crude refuse per day from a population of about 25,000. The plant which use the Dano system, is located near a sewage pumping station and is capable of utilizing 5 tonne of 92.4 percent moisture sewage detritus per day.

The receiving house, with a capacity of 31 to 35 M^3 (40 to 45 cuyds) of crude refuse, is equipped to minimize the dust problem. A conveyor delivers the refuse to a picking table and under a magnetic separator to extract cans and ferrous metals. The picking table has a speed of 27.5 m (90 ft) per minute and chutes are provided for textiles, non-ferrous metals, inert debris, glass bottles and jars. Dust extraction is provided at a picking table. On the lower floor, there are balers for tin and for textiles.

After metal extraction and picking, the remaining material are fed into Dano Bio-Stabilizer, being mixed with the detritus sludge. The drum rotates at 0.8 rpm. during the day and at 0.2 rpm. at night and over weekends; 5 days are required for passage through the drum with accompanying stabilization at about 57.5°C. The material is then screened

and a glass extractor removes the small inert particles. The power requirements are reported by Gottas [53], to be about 12-16 kilowatt-hours per tonne of refuse. He has also reported the composting period for mechanical digesters are to be 2-5 days for garbage or material containing little cellulose and having a low C/N ratio, and 7-9 days for material containing considerable quantities of cellulose and having a high C/N ratio.

Kupchik [10] mentioned a cost comparison of 21 mechanized composting plants in 10 Western countries. The average cost to process 1.016 tonne (one ton) of refuse was Rs. 34.2 ($ 4.55), of which capital service (amortization, interest and rent) amounted to Rs. 13.2 ($ 1.76), and operating expences Rs. 21.0 ($ 2.79). Based on comperative cost indices, it is evident that construction and operating cost in the U.S. would be considerably higher. The weight of compost produced was 46 percent of raw refuse processed, and the average income from sales amounted to Rs. 20.5 ($ 2.73) per 1.016 tonne (one ton) of compost or Rs. 6.75 (90 ¢) per 1.016 tonne (one ton) of raw refuse. Additional income from salvage material averaged about Rs. 1.5 (20 ¢) per 1.016 tonne (one ton) of raw refuse; only in Great Britain salvage income was substantial. It has also been reported by Kupchik [10] that in Europe and Israel the composting plants varied in annual rated capacity from 12,820 to 214,500 tonne (13,400 ton to 212,000 U.S. tons), and in

refuse actually processed from 9150 to 20,200 tonne (9000 to 199,000 tons) per annum. Sales income calculated per 1.016 tonne (one ton) of raw refuse processed, varied from none to Rs. 27.5 ($ 3.67). The highest selling price per 1.016 tonne (per ton) of compost was Rs. 49.75 ($ 6.63).

According to Gordon [19] the general attitude towards composting in the U.K. is that it is regarded as disposal method, it is not looked upon as a profitable operation which will attract private capital and consequently the economics of composting are compared against those of other disposal methods. The practice of controlled tipping (Sanitary landfill) is on the decline in many places in U.K. due to the decrease in available space and increase in haulage distances. Incineration is expensive and is being discouraged with the present compaign against atmospheric pollution. Perhaps the most important change to encourage the adoptation of composting treatment is the recent trend towards the use of organic fertilizers in agriculture.

2.6.5.2. Composting in India

Compost making is not a new science to Indian farmers. They have been doing it from the time immemorial. Krishna Rao and Savalappan [21] have mentioned that the two common methods of composting by Indian farmers are: Indore Method and Banglore Method. The process involved in the Indore method is the aerobic decomposition of organic

matters by microorganisms in open masonary pits. Refuse and night-soil are alternatively placed in 7.5 cm layer along half the width of shallow masonary pits (approx. 33 m long x 3.6 m wide x 1 m deep). The material thus placed is exposed to fresh air by turning it regularly (about 8 turnings) for a period of 2 to 3 months, followed by storing the same on the ground for about 1 to 1-1/2 months. In about 4 months the compost will be ready for use.

In the Banglore method, anaerobes act on the refuse and night-soil placed in alternate layers in earthen trenches. Each trench will measure approximately 10 m x 1.2 m x 1.2 m into which refuse and night-soil are placed in layers upto a total height of about 1.8 m, covered finally with 9 cm thick of earth. Thus the process involved in this method is anaerobic decomposition of organic matters. The period taken for decomposition is about 4 to 5 months. These unmechanized methods are still being extensively practiced in rural areas. However, there are limitations in their application in urban areas.

As for as the fertilizer value of the refuse is concerned Krishna Rao and Savalappan [21] have reported that average Indian city refuse has the following.

ITEM	CONTENTS, Kg PER CAPITA PER YEAR
Nitrogen	0.318-1.73
Potassium	0.123-0.665
Phosphorous	0.195-1.06
Organic matter	10.3-55.75

As it has been also mentioned by Krishna Rao and Savalappan [21] that in India, though there is not a single mechanical compost plant to speak at present, it is possible to install completely indigenous mechanical compost plants taking advantage of the technical know-how of advanced countries. They have mentioned that, however, the installation of first two such plants may involved some foreign exchange. For example, if a mechanised compost plant of capacity 200 tonne/day (16 hours operation) is installed at an approximate cost of Rs. 22.50 lakhs on "turn-key" basis, only about Rs. 3 lakhs will be required in foreign exchange. Cities like Calcutta, Bombay, Madras, Delhi and Poona are contemplating on installing such mechanised compost plants.

Henderson [54] conducted an economic studies on composting and landfill in India. It has been reported that the annual revenue from the sale of compost averages about Rs. 39,375.00 ($ 5,250.00) per year. The cost of operation is not known, but the cost of Banglore process is close to that of sanitary landfill operated with hand labor, so from this standpoint the revenue becomes a nett gain. Due to higher cost of construction and operation, the Indore process is looked on with less favour by local management and its economic advantages are questionable inspite of low wage level, about Rs. 2.4 (32 ¢) per day.

According to Gottas [53] the Indore or Banglore processes and their modifications are considered to have

limited applicability in U.S., but might be useful in special situations.

The net cost of mechanical composting depends greatly on the returns from sale of compost. At Nagpur and Poona, as it has been reported in [20], unsorted compost (which is 50-60 percent of raw refuse input) is sold at the depot at Rs. 8.50 to Rs. 11.25 per tonne.Where mechanical composting is adopted, the final compost would not be of the unsorted type and hence would fetch somewhat higher price, say Rs. 15.00 per tonne of finished compost or about Rs. 7.50 per tonne of raw refuse. This would bring down the effective cost of composting as shown in Table 2.17. Further effort is needed to reduce this cost.

2.6.6. Incineration Either Directly or After Separation

As defined by The Committee of Public Works Journal [46] incineration is used for reducing to ashes any or all combustible matter in refuse. Usually garbage, combustible rubbish, industrial refuse and dead animals are incinerated together. When combustible rubbish is burnt alone, the heat in large installations is employed for generating steam for power, domestic heating or for other purposes.

If garbage is incinerated, all combustion gases are passed through a secondary furnace at temperature of about 800°C to prevent odor and smoke nuisance. This is done

in an enclosed building, properly ventilated into the stack. Attention, is also given to air-pollution standards in designing an incinerator to avoid the fly ash problem.

Incinerators are of two types: (1) central incineration and (2) on-site incinerators. Central incineration means that the method is used by either a municipality or a private company to dispose of refuse at a plant to which refuse is brought from a relatively large community. On-site incineration is a widely used method of disposal for combustible refuse in Western countries for two principal reasons: (1) it is often desirable to dispose of refuse as soon as possible after it is produced to eliminate the need for storage facilities; (2) it does not require collection and transport services. On-site incineration applies to houses, apartments, stores, industries, hospitals, and other institutions.

It has been suggested by Meissner [55] that noncombustibles such as cans, bottles, metal containers, and tramp iron should be removed before the refuse is fed to the furnace. However, experience has shown that these materials help to keep the fuel bed open and porous so that the combustion air can pass through more rapidly. The same applies to crates, cartons, other rather bulky rubbish which burn more readily when they are not flattened or compressed. Shredders or hammer hogs have been tried in some cases but have been discarded for the above reasons. There best use

is when incinerating tree branches, Christmas trees, and similar metal-free trash.

The factors controlling the extent and degree of combustion have been listed by Nickelsporn [56] as follows:

(1) Supplying adequate oxygen in the form of air,

(2) Mixing air with refuse to start oxidation,

(3) Providing a high enough temperature to permit the oxidation, and

(4) Allowing adequate time to complete combustion.

It is necessary to have all four of these elements in order to have complete incineration. The lack of any one will result in incomplete combustion.

(1) Air supply: Without sufficient air the supply of oxygen will not be sufficient to permit complete incineration. Besides a limited supply of air results in a high temperature in the furnace, reducing the life of furnace lining.

(2) Mixing air and refuse: Proper mixing of the refuse is important to promote incineration. This requires a study of the method of introduction of the air into the furnace and the distribution of primary or undergrate air, as well as secondary or overfire air.

(3) Temperature: A sufficiently high temperature has to be maintained in the furnace to heat the refuse to the ignition point of the organic material and to sustain ignition. Furnace temperatures range from 655°C to 980°C (1200°F to 1800°F) and a mean value would seem to be about 832°C

(1500°F). This provides operating temperature in the furnace adequate to ensure complete incineration and yet low enough to prolong the life of the refractory. Temperature control is accomplished by the use of excess air in controlled quantities.

(4) Time for complete combustion: The time required for complete combustion is greatly reduced by having sufficient oxygen.

Nickelsporn [56] has also mentioned the criteria for designing the various systems in an incinerator.

(1) Capacity rating: Grate areas are rated by equipment manufacturers from their past experience. This rating determins the amount of refuse that can be safely incinerated per M^2 of grate surface in Kg per hour. In deriving this value, it is assumed that only a normal amount of hand stoking is required.

Following are the recommended rating in Kg of refuse burned per sq. m of grate area per hour of operation. Harringbone stationary grates (hand stoked) 195, inclined tilting grates (mechanically stoked) 293, and round grates (mechanically stoked) 342. Travelling grates are rated on the basis of 8.13×10^5 Kcal/hr-M^2 (300,000 Btu. per hr. per sqft).

(2) Furnace heat release: The normal heat release in furnaces operating under draft conditions is 177,500 to 308,000 Kcal per cum volume. An accepted figure of 0.70

cum per tonne of rated capacity has been used for the combined volumes of the furnace and combustion chamber. With a refuse having 2,220 Kcal/Kg as fires, this indicates a heat release of 118,000 Kcal per cum per hour of primary and secondary chambers.

Some of the common design criteria for incinerators have been given by Clark [18] as shown in Table 2.15(a) and (b).

(3) Air requirements: As most municipal refuse has a combustible content similar to cellulose, $C_6H_{10}O_5$, in chemical composition, the theoretical air requirement has been calculated as 5 Kg of air per Kg of combustible as fired. This calculation is based on the atomic weights of oxygen, hydrogen, and carbon and on the proportions of oxygen and nitrogen in the air. However, in actual practice it is desirable and practical to provide 100 percent excess air, or 10 Kg of air per Kg of combustible as fired.

(4) Gas weights and velocities: The total gas weight is the sum of the following items; Total air supply; total moisture in refuse; and total combustible in refuse.

Recommended gas velocities in meters per minute are as follows: Furnace outlet 550; flues 550; settling chamber 183; and chimney 328. These velocities are calculated with gas temperatures in degree C. as follows: Furnace outlet 550°C, settling chamber 458°C, and chimney 396°C.

(5) Furnace heights: In general, the greater the furnace

TABLE 2.15(a) [18]

Classes of Refuse	Grate loading Kg per hr per sqm
Combustible rubbish	244
Garbage and combustible rubbish	318
All classes collected together	366

TABLE 2.15(b)

Class of refuse	Furnace loading		Fan capacity
	Kg of refuse per sqm of grate area	Kg of refuse per cum of combustion volume	Kg of air per Kg of refuse
Combustible rubbish	244	30.4	3.0
Garbage and combustible rubbish	318	38.4	7.5
All classes collected together	366	52.8	6.0

height, the better the design. On municipal batch fed incinerators, in order to keep the building height low, 3 m (10 ft) has been established a satisfactory value for the distance between the grate line and the under-side of the furnace arch. With a travelling grate design, heights upto 5 m (16 ft) are used.

(6) Primary and secondary air: Primary air, which is air supplied under the grate area is approximately 80 percent of the total air supply. Primary air is furnished by either forced draft fans or natural draft. Secondary air, which is overfire air, is normally provided by natural draft by means of port openings above the grate surface. A portion of secondary air is furnished through jets using blowers. These overfire air blowers and jets provide air turbulence with high velocity air streams, providing better refuse and air mixing and consequently improved combustion.

(7) Air-flow resistance of stoking grates: The opening on the stoking grate surface offer some resistance to the air passage. Grates having high resistance to air flow are normally used in combustion of coal and other solid fuels. These grates require forced draft fans which provide equal air distribution over the grate surface regardless of refuse distribution.

The advantage of grates having high air-flow resistance is that more intimate mixing of combustion air and the refuse occurs. The grates having low-flow resistance

have the advantages of simplicity of operation, lack of noise and saving in maintenance and electric power by not using a motor driven forced draft fan.

In recent years, incinerator design has been markebly influenced by the need for more efficient operation and lower costs. This has led to the development of continuous-feed and mechanical stoking, mechanically controlled overfire and underfire air, facilities for fly ash removal, systems for continuous quenching and discharge of incinerator residue, and the use of sectionally supported walls and hung arches with high quality refractory linings. These new developments have made possible installation of larger incinerator with a lower potential for creating nuisance and the advantage of lower operating costs.

2.6.6.1. Incineration after separation

It has been mentioned by Meissner [55] that sometimes there is salvage value in the cans and tramp metal, which may be picked-out of the residue by magnetic pulleys or cranes, or in unburned paper, rags and cans for their tin, zinc, solder, and iron content; however, often municipal plants are designed to incinerate all the refuse collected except that which is too large too pass through the furnace or is hazardous (such as oil drums or similar containers that may contain explosive substances).

Since incineration is associated with air-pollution and fly ash problems, therefore, to eliminate chances of air-pollution, various units such as multiple cyclones, electrostatic precipitators and wet scrubbers are also provided and chimney height is properly controlled.

2.6.6.2. Incineration in western countries

Ludwig et al [57] have reported that many U.S. communities, particularly the larger one, use municipal incinerator to reduce the volume of the wastes. Noncombustibles are either collected separately or passed through the furnace along with other refuse. Incineration reduces the rate at which land is used by one-half to one-third of that required for sanitary landfilling. The operating cost of large scale incinerator generally runs from Rs. 30.00 ($ 4) to Rs. 33.75 ($ 4.5) per tonne including ash-disposal costs.

Porteous [58] has mentioned that in 1970, the Greater London Council commissioned an incinerator plant at Edmonton at a cost of Rs. 15.28 crores (£ 7.64 million). One an average the incinerator takes about 1350 tonne (1333 tons) of refuse a day and outputs some 265 tonne (259 tons) of clinker, 149 tonne (147 tons) of metal and 76 tonne (75 tons) of fly ash. So the total of 490 tonne (481 tons) represent a reduction in weight of 64 percent. The cost of adopting a modern incinerator plants are considerable at Rs. 60.00 per tonne (£ 3.04 per ton) of daily capacity. Although in the actual installation the refuse is used as

a fuel to raise steam, the economics of this are very marginal.

It has been pointed out by Engdahl [59] that operating costs also varied widely, depending on the type of refuse burned and the thoroughness of burning, the degree of sanitation controls exercised, the type of incinerator plant and the extent of its mechanization, the wage scale and amount of fringe benefits, and the productivity of labor and efficiency of management. Operating costs for six cities were compared, as shown in Table 2.16.

In European countries and U.S., the heat of combustion has been put to use in various ways. Some units supply the heat for heating of residences and other establishments. However, the more common method is to utilise this heat for power generation which can be either sold outside or used in the plant itself. All these measures are intended to reduce the cost of working of incinerator.

2.6.6.3. Incineration practice in India

In India the practice of disposal of refuse by incineration is not being adopted except at some places where the open burning of the refuse is done. The main reason for not adopting incineration is that the refuse from the Indian cities has got quite a low calorific value as compared to the Western countries. However, since the cost of landfilling is increasing day by day in large Indian

TABLE 2.16: OPERATING COSTS FOR MUNICIPAL INCINERATOR IN SIX U.S. CITIES[a] [59]

CITY	COST PER TONNE OF REFUSE PROCESSED
1. Philadelphia	Rs. 31.0 ($ 4.24/ton)
2. Washington DC[b]	Rs. 16.65 ($ 2.28/ton)
3. Detroit	Rs. 31.40 ($ 4.30/ton)
4. New York City[c]	Rs. 40.05 ($ 5.55/ton)
5. Milwaukee	Rs. 47.40 ($ 6.49/ton)
6. Los Angles	Rs. 22.84 ($ 3.13/ton)

a. Cost for one plant in each city in 1959, except for New York, where the cost is 1958 average for three plants.

b. Does not include amortization cost.

c. Cost computed on the basis of tonne (tons) burned. (Amount charged minus residue).

cities due to longer haulage distances, authorities have given some thoughts on installing incinerator in some of the large cities of India.

As reported by Fernandes [37] that if the whole of Bombay's refuse were to be incinerated, the annual cost of auxilary fuel itself would be about Rs. 1.18 crores. The capital cost for installing the incinerator would amount to Rs. 10 crores to Rs. 30 crores depending upon the sophistication of the incinerator.

As it is mentioned in the report [20] and can be seen from the Table 2.17, the cost of incineration is the highest among all methods of disposal (mainly due to the auxilary fuel required for the low calorific value encountered). The cost of fuel alone accounts for Rs. 25 per tonne in the table shown. An incinerator can be located even in the habited localities, saving in transportation cost can be achieved. But even after deducting this saving for Calcutta conditions and the money recovered by the sale of electricity, the cost of incineration is between Rs. 25 to Rs. 30 per tonne as shown in Table 2.17. Incineration would obviously be feasible if the refuse was of such a high calorific value (as in the Western countries) to reduce use of auxilary fuel. Alternatively, incineration could be considered for specific areas of a city where high calorific value of refuse is encountered.

TABLE 2.17: [20]

Method	Land needed for 2 years operation @ 100 T/day	Gross operating cost in Rs/tonne			Net cost Rs/tonne after sale of product
		Land*	Other	Total	
1. Uncontrolled dumping	45,000 m^3	1.95	0.55	2.5	2.5
2. Manual composting in pits of 1 m depths	12 hact.	0.60	5.4	6.0	No profit no loss
3. Sanitary landfill	20,800 m^3	1.30	6.90	8.2	8.2
4. Mechanical composting	1.6 hact. for plant. 12,300 m^3 for disposal of non-combustible	0.4	14.35	14.75	7.25
5. Incineration					
Without heat utilization	0.8 hact	0.8	41.7	42.5	30.0
With heat utilization	1.2 hact	1.2	46.0	47.2	23.0

* Land cost assumed @ Rs. 25,000 per hactare for items 1-4; @ Rs. 5 lakhs per hactare for item 5. Average depth of filling assumed as about 3 m.

2.6.7. Grinding and Adding to Sewage

The disposal of food wastes by grinding - the process by which garbage is changed into small particles and flushed into sewers - has been widely accepted in recent years in Western countries. Eliminating garbage on the premises as it is produced is considered the ultimate in convenience and sanitation. The on-site grinders reduces the time garbage is stored on the premises to an absolute minimum.

Garbage grinders are usually divided into three classes according to their use. Home grinders are exactly what the name implies. Commercial and institutional grinders are large units used in restaurants, hospitals, and food processing establishment such as a produce center or supermarket. Municipal grinders are even larger and are used to dispose of garbage collected by conventional means and taken to a central grinding stations.

A number of cities in advanced Western countries dispose of garbage by grinding it and discharging it into the sewerage system. In such cases, tin cans, bottles, broken glass ware and crockery, metals, ashes and similar refuse are kept separate. Their inclusion makes manual or mechanical sorting necessary at the disposal plant, and this is a costly operation. In the grinding process small amounts of paper are not considered objectionable.

Some times refuse is also ground to facilitate its'

disposal. It has been mentioned by Meyer [60] that the Heit-Gondard Process automatically selects out nongrindable refuse and grinds the rest. It thus makes possible the combined collection of any refuse combustible or non-combustible. By grinding and mixing the refuse to a uniform composition, it facilitates landfill, incineration, and composting operations. It also facilitates salvaging and makes possible shorter haul distances through the use of milled material at small incinerators and landfills closer to population centers, than is feasible with the large operations needed for unground refuse.

2.7. CRITERIA FOR SELECTION OF HANDLING AND DISPOSAL SYSTEM

The technology of solid wastes management has developed, as have most other technologies, by gradual improvement of equipment and techniques to alleviate the various problems faced. There are two basic criteria for selection of handling and disposal system of refuse.

1. Efficiency, and
2. Economy

Efficiency and economy of handling and disposal system of refuse depend upon the methods adopted in initial handling, collection, transportation and disposal of refuse. The selection of procedures adopted during handling and disposal of refuse are as follows, keeping in view the efficiency and economy of the various systems.

2.7.1. Selection of a Collection System

Untill refuse is collected, responsibility for its' disposal cannot pass to the municipal forces; up to that time the house-holder is in sole charge. The manner in which it is stored, prepared, and presented for collection is an important factor in determining the effectiveness and efficiency of the collection operation. At one extreme, the refuse may be carefully separated by classes; the garbage carefully drained, wrapped, tied, and placed neatly in water-tight covered cans; the rubbish placed in covered receptacles or carefully bundled and put beside the containers; and the ashes kept in covered metal cans. At the other extreme, all refuse may be dumped without discrimination in a heap in a back yard or alley. It is obvious that in the latter case the work of collecting and disposing of it is difficult and expensive; to say nothing of the nuisance and the menace of the public health that is created.

The character of tne refuse collection service varies also with the frequency with which several classes of material are removed from the householder"s premises. Within reasonable limits, the more frequently collections are made the more satisfactory and convenient it is for the citizens. When refuse is removed often, fewer and smaller containers are needed, garbage does not putrefy in the cans, and it cannot serve as a breeding medium for flies and other insects,

nor as food for rodents.

The proper frequency to give the most satisfactory and economical service is governed by the amount of refuse that is collected, the climate, and the demands of citizens. For the collection of refuse containing garbage the maximum period between collections should not be greater than:

1. The normal time for the accumulation of the amount of refuse that can be placed in a container of reasonable size;
2. The time it takes fresh garbage to putrefy and to give off foul odors, under average conditions of storage;
3. The length of the fly-breeding cycle (about ten days).

The frequency for the collection of rubbish and ashes generally is based on the size of containers, the amount produced, and the funds available.

2.7.2. Selection of Mode of Transportation

In planning transportation methods and selecting proper equipment, the distance that refuse must be hauled is of prime significance. Under normal conditions, the shorter the haul the easier are the planning and supervision of refuse collection operations, and the lower is the cost of the service. Long haul requires more and frequently larger equipment, and occasionally the refuse must be transferred from the collection vehicles to others for transport to the disposal points.

In explaining the cost involved, the distance the refuse must be hauled may be less significant than the amount of time required to haul a load to a disposal site and return, because the conditions of travel differ considerably and time lost at the disposal points vary. Certainly where all or substantial part of the haul is through urban areas, the speed of travel will be much less than on rural highways.

It is not always feasible or economical, and sometimes it is not even possible, to haul refuse in the collection vehicles direct to the disposal sites. Supplemental transportation may be considered in two general classes: (1) The refuse bodies or vehicles are hauled by one kind of equipment during collection operations while a different piece of equipment relays them to the disposal site. (2) The refuse is shifted from the collection vehicles to other kinds of transportation equipment. The material is transferred at loading stations, relay stations, or transfer stations either by dumping it directly from one vehicle to another or by dumping it into hoppers and then into the transfer vehicles.

The Transfer Loading Station is an intermediate stage in refuse disposal. The installation becomes necessary when the final disposal site is at so great distance from the collection area that direct haul by collection vehicles becomes uneconomical. That distance can only be established in the light of local knowledge, for whereas it may be operationally and economically sound to use large capacity

vehicles doing a minimum number of loads per day in one area, much smaller vehicles doing a greater number of loads will be required in another.

The kinds of refuse collection vehicles depend on the quality and quantity of refuse. Open top trucks are being replaced rapidly in the collection of mixed refuse by the more sanitary enclosed compactor trucks in Western countries. Many open top trucks however, are still being used, especially in the smaller cities, for collecting mixed refuse. There are several important advantages in the open-top truck. First, cost is usually less, and they are more economical to operate than other kinds of trucks.

Compactor type to truck possesses advantageous features such as low loading height and ability to crush and compact the refuse containing e.g. wooden boxes, cartons, tin cans etc., thus permitting more materials to be loaded in the same size body. Such type of vehicles require less number of loading or unloading personnel because compaction and unloading of the refuse are done mechanically. Less crew also adds to the economy in the transportation system.

2.7.3. Selection of Disposal System

The refuse collection system obviously must be carefully coordinated with the system of disposal. Some times disposal methods can be selected so that the most economical and effective collection practices can be employed.

More frequently, however, there are definite limitations on the possible disposal methods and on the location of disposal sites, and it becomes necessary to design the collection system to fit the arrangements for disposal.

It is important to remember that whilst the primary object will be to find the most suitable method of disposal in relation to the type of refuse to be received, thereby assessing how best to maintain good health and amenity, there are other factors which must be studied, nearly all of which are concerned with local conditions or the probable effect upon those conditions of any selected method.

2.7.3.1. Landfilling

There are, a number of features are listed by Stirrup [61] which must be considered in the value of any site for landfill is to be assessed with reasonable accuracy:
Length of haul from collection area and traffic conditions enroute; accessibility for the type of transport in use; the need to improve access and the probable cost of work required.
The nature and class of building in the vicinity.
The direction of the prevailing wind and the probable steps necessary to protect those buildings from nuisance.
The availability of public utility services for the provision of heat, light, power, water and transport for employees.
Estimated total capacity for the reception of refuse and covering material. Is covering material available on site?

If not, where can it be obtained and at what cost?
Estimated life.
Engineering required such as culverting, bridging, drainage, protection of water course, etc.
Assessment of site usage in relation to limitations as to types of material which may have to be imposed by reason of physical or local conditions.
Future use after completion of landfill.
Probable cost of acquisition, operation, ancillary work, completion work.
Estimated value on completion.

2.7.3.2. Composting

The degree to which utilization can be effected is dependent not only upon conditions in the community served, but also in relation to the distance from the area in which the recovered material may be usable. If there is a particular local need and refuse is suitable in nature, disposal by utilization becomes the prime consideration. A farming area requiring to maintain its soil in a healthy condition must surely welcome compost.

During composting, the main thought must be directed to preserving a carbon-nitrogen ratio of about 30:1 to maintain speed of production, and when finished the ratio should be about 20:1 if nitrogen available in the soil is to be preserved for plant food. If during the preparation of

compost, the operational precautions are observed, foul odors will be prevented, flies discouraged and pathogenes destroyed, whilst the resulting material will be of good quality and ready for use.

Though the efficiency of mechanical composting plant is more than the manual composting but the initial installation cost of a mechanical compost plant is quite high compared to manual compost plant. The economy of mechanical composting plant lies in the sale of compost.

2.7.3.3. Incineration

The heterogeneous mass of refuse has such differing physical and combustible characteristics in its individual components that it is inevitable that capital and operational costs will be high if disposal by incineration is to be properly performed. Adequate preliminary investigation is, therefore, of the utmost importance.

Primary considerations should commence with the physical analysis of refuse in order to establish the main characteristic, and further tests have to be taken which will show the maximum and minimum calorific values of the mass of crude refuse, its moisture content and that of the vegetable and putrescible matter contained within it. This can be accomplished over relatively short periods at the appropriate peak of each seasonal change.

In order that the plant may achieve the desired

results and maintain a steady throughput without excessive capacity, the rate of input is to be studied. In a project demanding high capital expenditure, it is even more necessary to look to the probable future developments, such as any increase or decrease which is likely to occur in the size of community, and the changes in nature of refuse which it is possible to forecast because of the development of clean air regulations or trends in the packaging of food stuffs etc.

The geographical situation of the plant is naturally of importance if operational economy of the collection service is to be maintained, or improved to offset some of the costs of refuse disposal. The first endeavour is undoubtedly be to find a site providing minimum haul for the maximum number of vehicles.

CHAPTER III

3.1. CURRENT REFUSE HANDLING AND DISPOSAL SYSTEM IN KANPUR CITY

Kanpur is the eighth largest city in India; and largest in Uttar Pradesh with a population of 1.274 million (according to the census of 1971). Kanpur is one of the big industrial and commercial cities of India having various types of big industries such as textiles, woolen mills, tannery, sugar and iron and steel. Due to the rapid industrialization the growth in population within the past few decades has been quite considerable. Fig. 3.1 shows the growth of population of Kanpur city from 1901 to 1971.

The city of Kanpur covers an area of 320 sq km and includes the area under jurisdiction of Kanpur Nagar Mahapalika as well as the cantonement area, under the control of Kanpur Cantonement Board. The Kanpur Nagar Mahapalika area of the city is divided into 36 wards on the basis of corporation constituencies, out of which only 31 wards of these are being served by the Kanpur city refuse disposal system. The population of the 31 wards being served for refuse disposal is 0.944 million. It shows that only about 74 percent of the total population of the city is provided with facilities for the disposal of their refuse by the city administration. Table 3.1 shows the numbers of wards and their population.

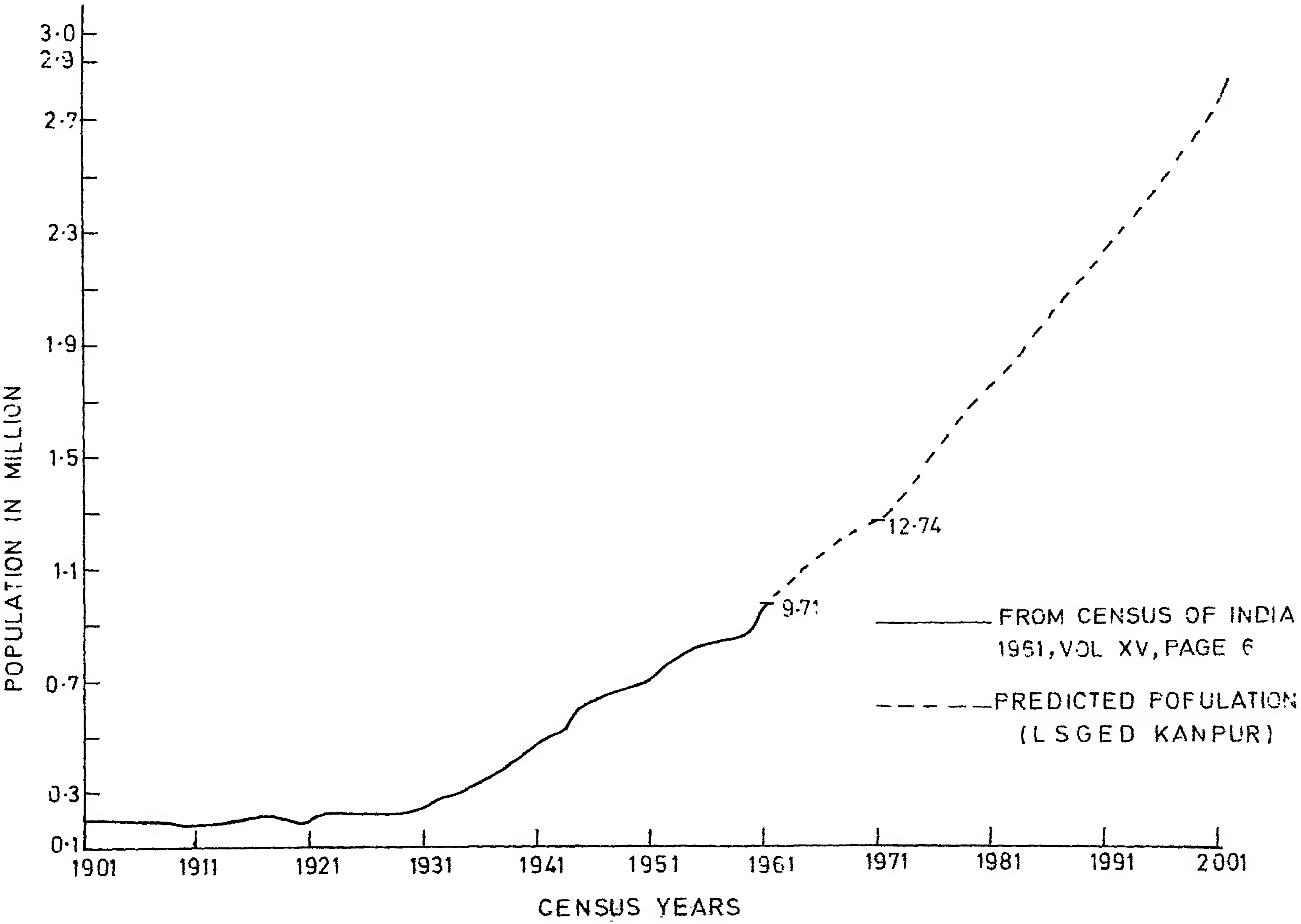


FIG. 3·1 POPULATION OF KANPUR (1901–2001)

TABLE 3.1[1]

Ward No.	Name of ward	Population	Ward No.	Name of ward	Population
1	Nawabganj	40,206	19	Pared	28,678
2	Benazabar	25,659	20	Kernailganj 1	29,450
3	Aryanagar	25,465	21	Kernailganj 2	30,952
4	Gwaltoli	26,466	22	Chamanganj	32,425
5	Sooterganj	23,563	23	Sisamau 1	31,465
6	Civil lines	20,612	24	Sisamau 2	22,199
7	Patkapur	24,116	25	Jawaharnagar	27,026
8	Feelkhana	24,011	26	Nehrunagar	38,144
9	Bangali mohal	24,622	27	Kaushalpuri	30,390
10	Maheswari mohal	18,912	28	Darshan Purwa*	29,473
11	Jernailganj*	17,169	29	Hariharnath Sastrinagar	55,075
12	Harbans mohal	27,156	30	Govindnagar	45,504
13	Moti mohal	22,290	31	Juhi Hamirpur Road	59,026
14	Koolibazar	11,061	32	Babu purwa 1	47,206
15	Zareeb chowki	28,053	33	Babu purwa 2	38,895
16	Laxmi purwa	27,895	34	Jajmau*	50,773
17	Anwarganj	35,599	35	Chakeri*	36,832
18	Dalel purwa	32,917	36	Kalyanpur*	52,640

1 Data collected from the Office of the Municipal Corporation, Kanpur city.

* Wards are not being served by the refuse disposal system.

3.1.1. Organization of Refuse Department

The refuse department of the city is organized under the Kanpur Nagar Mahapalika. The executive head of the Kanpur Nagar Mahapalika is the Mukhya Nagar Adhikari, who looks after all the organizations coming under Nagar Mahapalika. Under him there are six different sections with their respective incharges as shown in Fig. 3.2. The Nagar Abhiyanta (City Engineer) incharge of electrical and mechanical departments in the Nagar Mahapalika, who is under one of these six incharges (Up-Nagar Adhikari), is the executive head of the refuse department, looking after the collection and disposal of the solid wastes from the city. Under him there is a section incharge known as Transport Superintendent whose job is to organize and execute the collection, transportation and disposal of the refuse. The refuse section employs 510 persons in different cadres of Transport Superintendent, overseers, clerical staff, drivers, loading and unloading personnel, jamadars, and chowkidars. A detailed organization of the refuse department is shown in the Fig. 3.2.

3.1.2. Methods Adopted for Refuse Handling and Disposal in the City

Following are the methods adopted for refuse handling and disposal in Kanpur city.

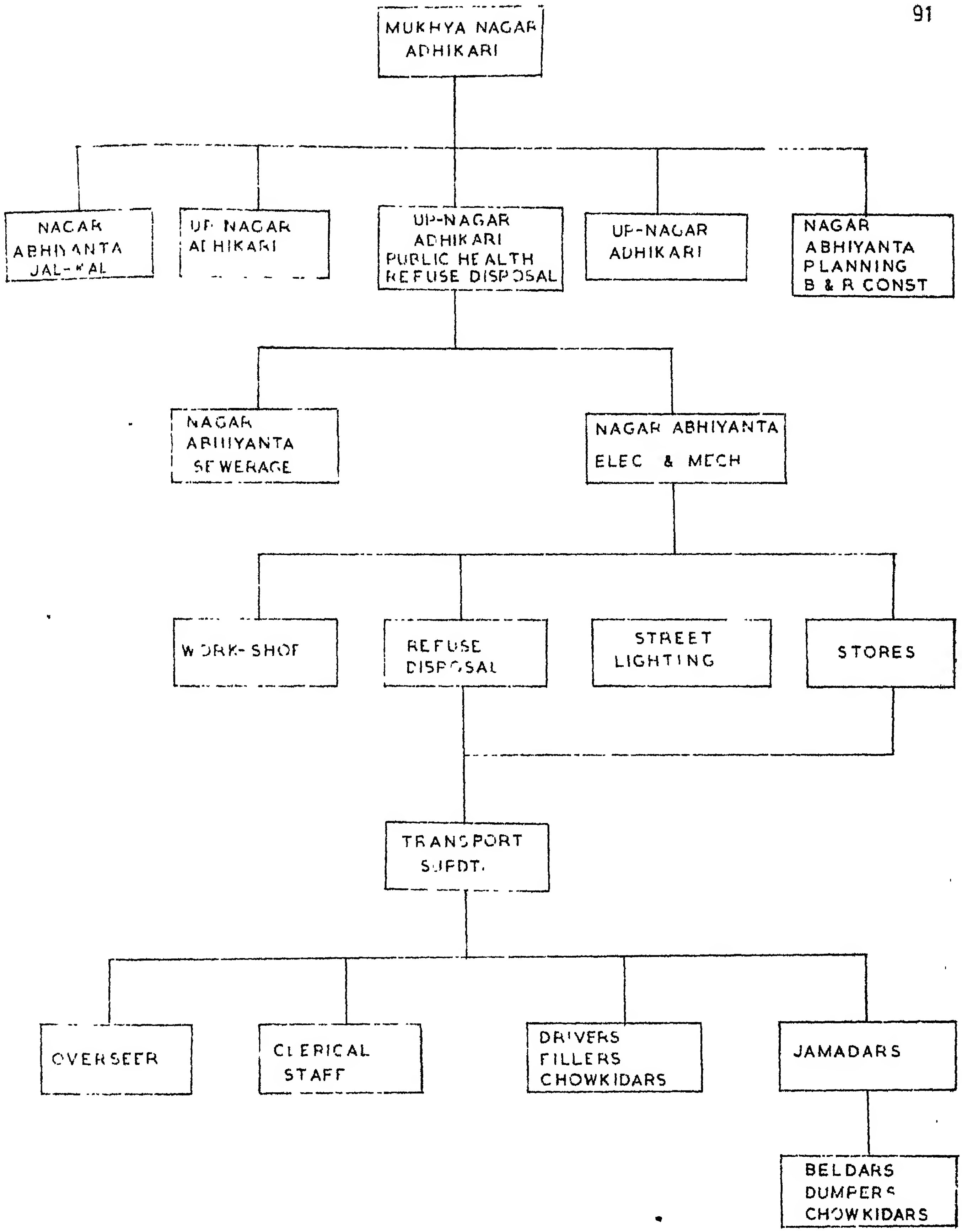
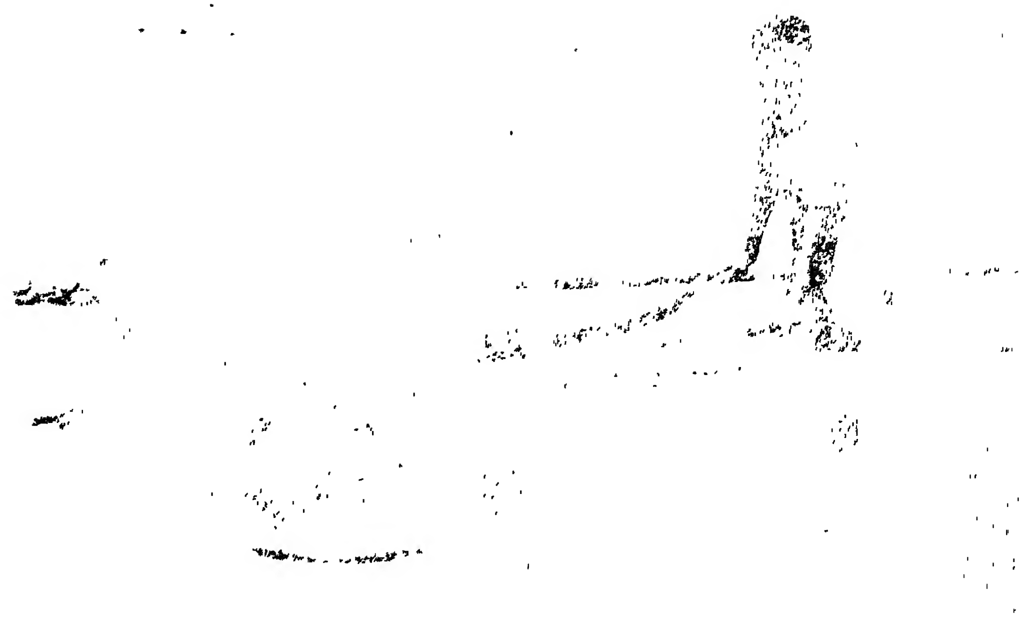


FIG. 3·2 FLOW CHART SHOWING THE ORGANIZATION OF REFUSE DISPOSAL DEPARTMENT OF KANPUR NAGAR MAHAPALIKA

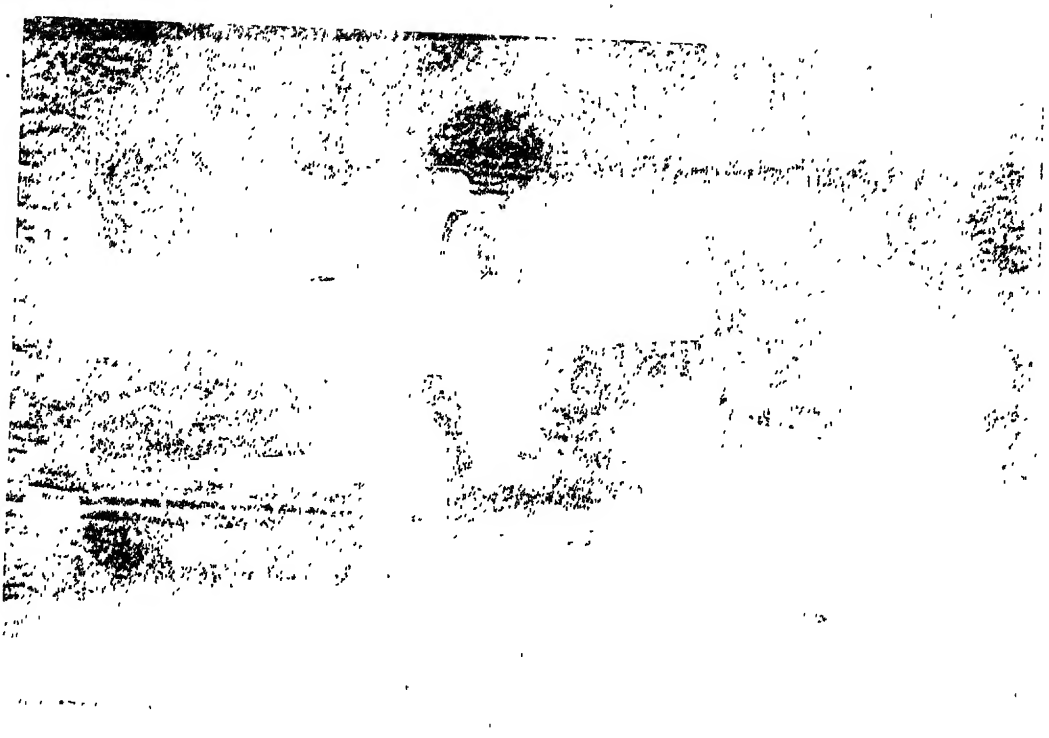
3.1.2.1. Collection

The areas of the refuse generation in the city can be divided into three categories: residential, commercial and industrial.

(1) Residential Areas: The quantity of refuse generated by each family and the mode of its' handling at the source depends on the standard of living of the particular family. The composition of the refuse also depends on the domestic activities, whether the refuse is from kitchen, house sweepings, or from garden sweepings. The place and the frequency of collection of refuse from these sources varies according to the quantity and composition of the refuse. For example the garbage from kitchen will generally be stored in some sort of garbage bins often improvised from empty cans, old buckets etc. whereas the house sweepings and garden sweepings are either collected in the corner of the yard or directly thrown on the road side collection points forming a garbage heaps. In the high living standard areas such as Civil lines, Swaroop nagar, and Arya nagar, refuse generated by each family is collected in a small, often improvised garbage bin placed at the rear side of the house. Many a times this is no more than a used 10 Kg kerosine tin, though some times, it may be a specifically made 0.1 to 0.15 M^3 garbage bins of G.I. Sheets. The refuse container is provided by the house owner himself. On every day in the morning the collected refuse in the container is emptied on



(a)



(b)

FIG. 3.3 REFUSE COLLECTION (a) AND [illegible]
(b) ARRANGEMENTS AT [illegible]

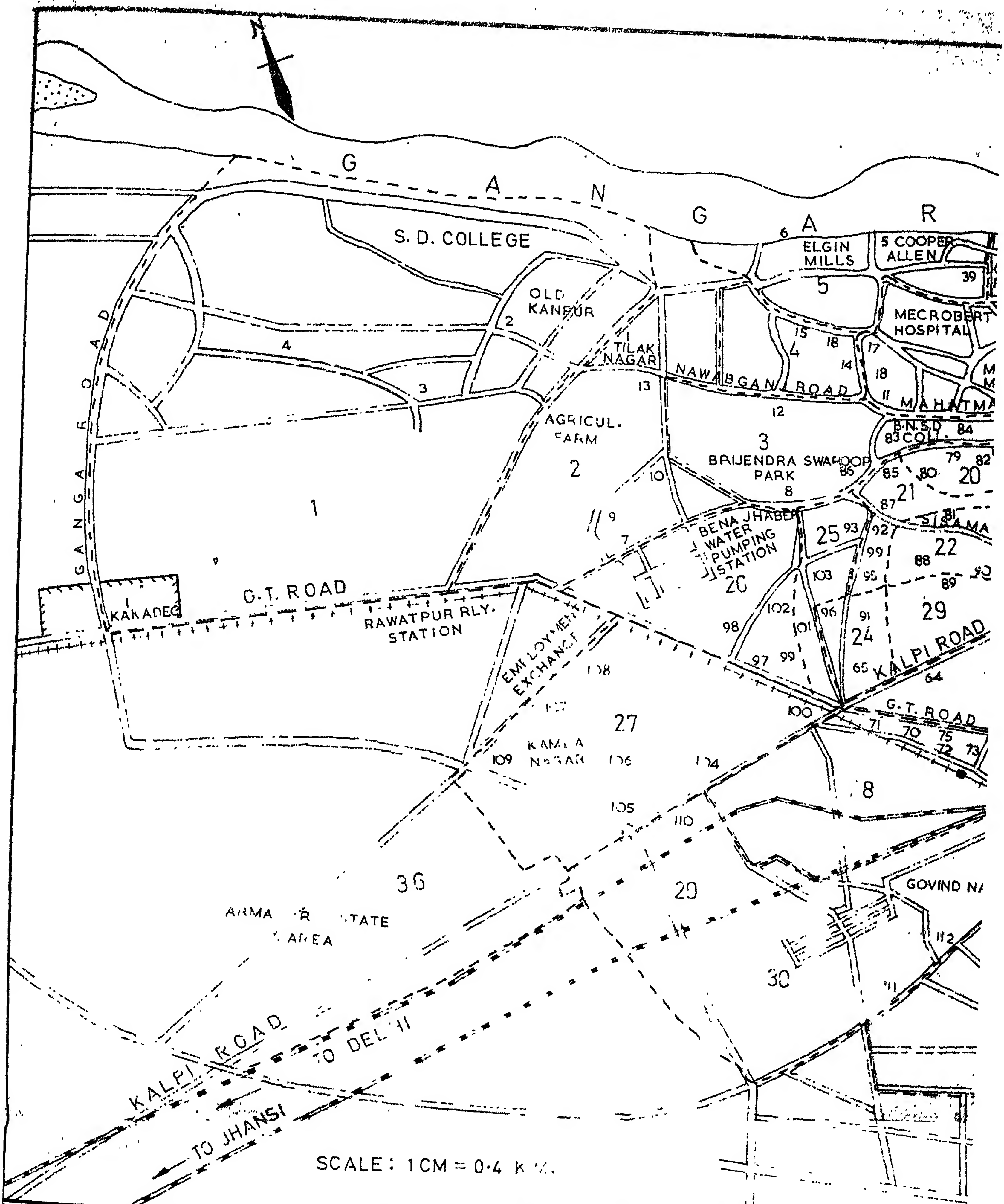
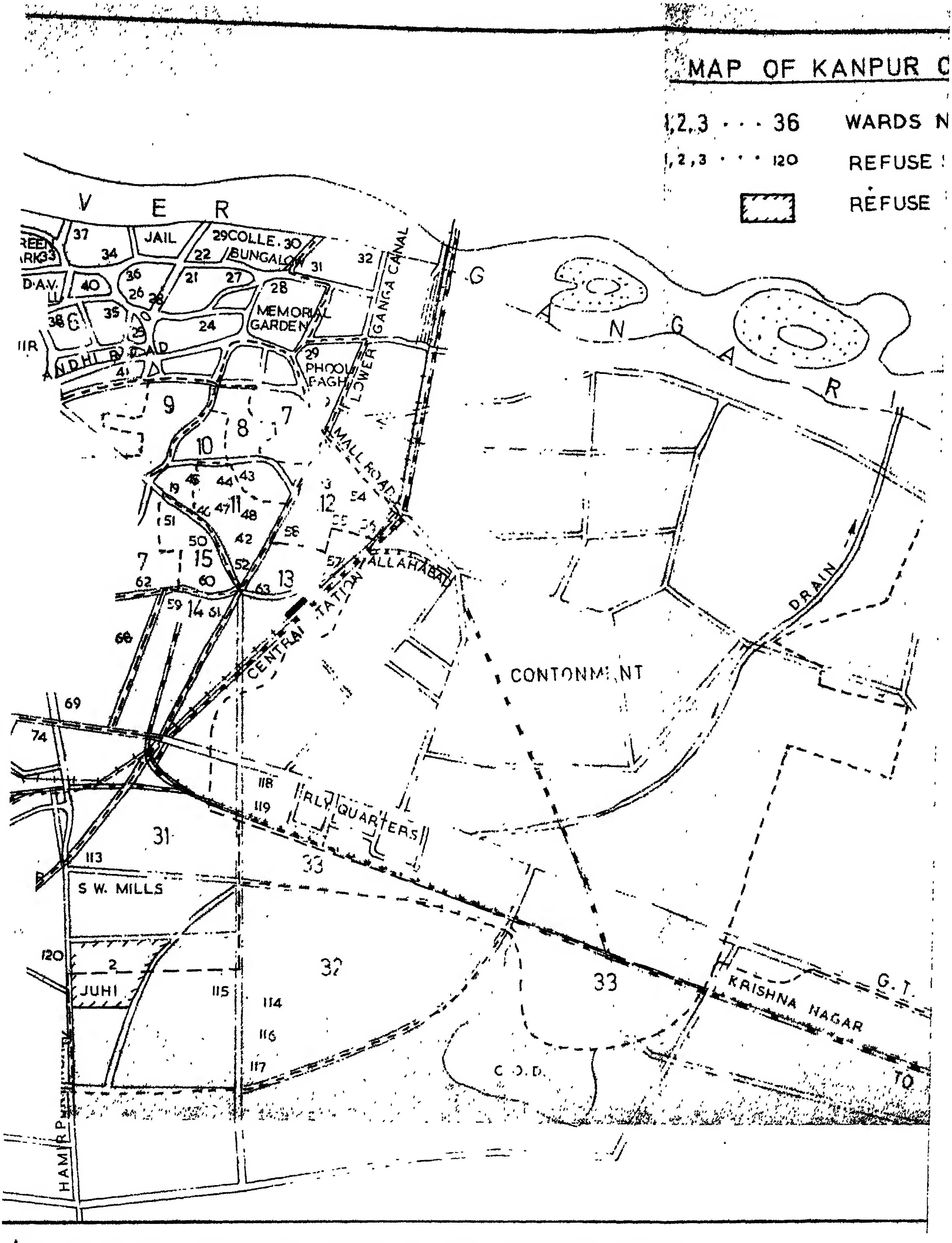
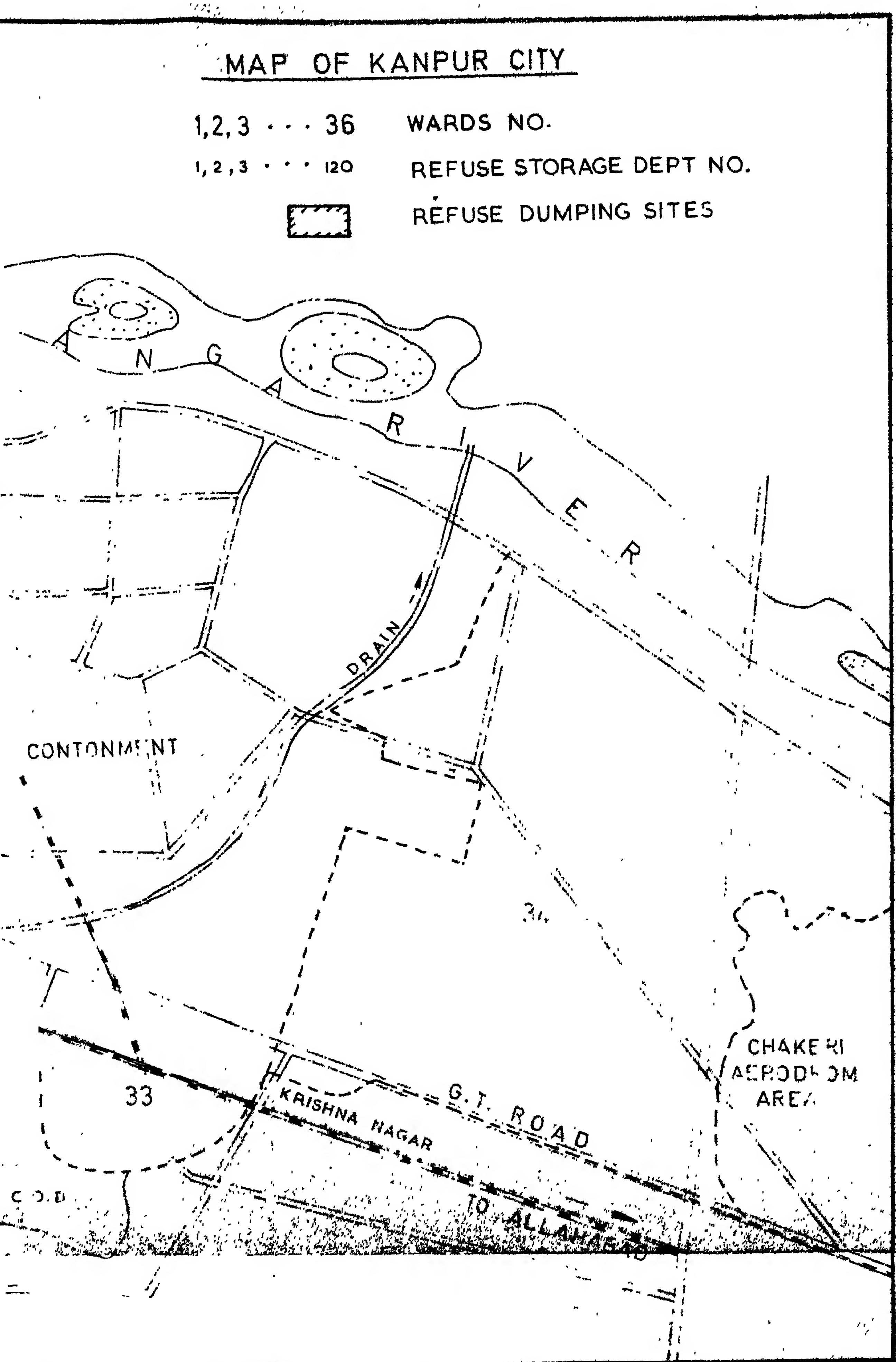


FIG. 3·4 LOCATION



OF REFUSE STORAGE DEPOTS AND DUMPING SITES



DUMPING SITES

heaps situated on the road sides or on the side of lanes. In these areas also, garbage bins are emptied once in a day usually in the morning by the householder himself, on the garbage heaps.

From garbage heaps, as mentioned above, the refuse is collected at the corresponding nearest storage depots before being taken to the dumping grounds. Each storage depot serves a population of about 4 to 8 thousands depending upon the density of population and the quantity of refuse generated by each family.

The location and maintenance of the storage depots are not all too satisfactory. In many instances these are located at places where easy access to the truck is not afforded such as depots no. 42, 51, 91. This is a serious drawback since a considerable amount of labor and time is wasted in carrying the refuse from the depots to the waiting trucks. The afore said depots are situated on narrow lanes and in thickly populated areas.

In the areas where the quantity of refuse generation is more such as Feelkhana, Patkapur, Chamanganj, the refuse is removed from the depots daily. In areas, which are not thickly populated such as Civil lines, Aryanagar, Swaroopnagar, where the refuse generation is lesser, the refuse is removed from the depots on alternate days. When the further transportation to the dumping ground is not prompt from the above said areas, this gives rise to severe problems due to

due to accumulation of refuse on depots.

(2) Commercial Areas: Following are the places from where the refuse is generated in commercial areas:

(i) Shops

(ii) Restaurants

(iii) Cinema houses.

The collection method and frequency of refuse on the above places varies with the quantity and nature of the refuse generated. Such as in the case of shops where, the quantity of refuse generated in lesser as compared with the other two places, refuse is collected in garbage bins, and is thrown once in a day on the nearly situated garbage heap. In restaurants where the quantity of refuse generated is more and of putrescible quality, it is collected in garbage bins and emptied at frequent intervals depending upon the quantity of refuse collected. The main commercial areas in the city are Pared, Phoolbaag, Anwarganj, etc. As far as the refuse collection from cinema houses is concerned the sweeping is carried out once in a day before starting of thw shows, and the sweepings collected in a garbage bin from where it is taken by sweepers to the garbage heaps.

(3) Industrial Areas: There are many big industries in the city such as Lal Imli Woolen Mills, Elgin Cotton Mills, Swadeshi Cotton Mills etc., which have their own arrangement for the disposal of industrial wastes. Refuse generated by these industries is directly transported to the dumping

grounds by 3 tonne open trucks, provided by the industrial authorities. As far as small industries are concerned, refuse is collected in the same manner as described in the commercial areas depending on the quantity and nature of refuse generated.

3.1.2.2. Transportation

Transportation of refuse in the Kanpur city by open trucks is being carried out since last 40 years. In the year 1971, the refuse department had the following equipments for the refuse transportation from the refuse storage depots to the dumping sites.

	Equipment	No.	Specifications
1.	Open trucks	48	3 tonne open trucks purchased second hand in auction
2.	Dumpers	6	3 tonne open-type.

Recently in the month of January 1972, refuse department has introduced new equipments for loading and transportation of refuse. These are:

	Equipment*	No.	Specifications
1.	Loader	1	Escort-Hi DRA 600 Front end loader 49 H.P., loading capacity 600 Kgs bucket size 0.6 cum
2.	Tractor	2	Tugger-50 49 H.P.
3.	Trailor	10	5 tonne tipping trailer, 4 wheeled

* Equipments were manufactured by Escort Limited, Faridabag, India.

But at present, these new equipments are not being used, because the proper arrangements for the trailors have not yet been made. The plans are under progress. Only loader is being used for loading the refuse from the storage depots on to the open trucks. At present refuse section operates a fleet of 45 open trucks including dumpers for the purpose of refuse transportation, the rest of the vehicles are under repair and maintenance. On an average each truck makes four trips in a day. Besides the driver a crew of six persons is engaged with each of the truck. Transportation of the refuse from most of the areas is carried out regularly. In areas which are not thickly populated and quantity of refuse generation is less e.g. Nawabganj, Civil lines, Aryanagar, the refuse is transported on alternate days, depending upon the quantity of refuse collected in storage depots. City refuse is transported on to one of the two dumping sites. For each dumping site, an easy approach route is followed by the drivers from the storage depots. For the easy approach to the dumping sites by trucks, the number of storage depots are alloted into two groups. Out of 120 storage depots, 56 are being served for dumping site no. I and 64 are being served for dumping site no. II. Fig. 3.4 shows the locations of dumping sites. Each of the trucks is assigned for one or more than one depots depending upon the quantity of refuse on the storage depots. When a truck is to be loaded with refuse, it stands just near the

depot and a crew of six men loads the refuse onto the trucks with the help of baskets and shovels as shown in Fig. 3.3(b). At the depots where the easy access for the truck is not possible e.g. depot nos. 42, 51, 91 the truck waits at a distance from the depot and the crew loads the refuse manually. Refuse loaded on the truck is emptied on the dumping sites manually by the same crew, except the dumper trucks. After unloading the refuse the truck again goes to the other collection depots and transports the refuse to the dumping sites.

3.1.2.3. Disposal system

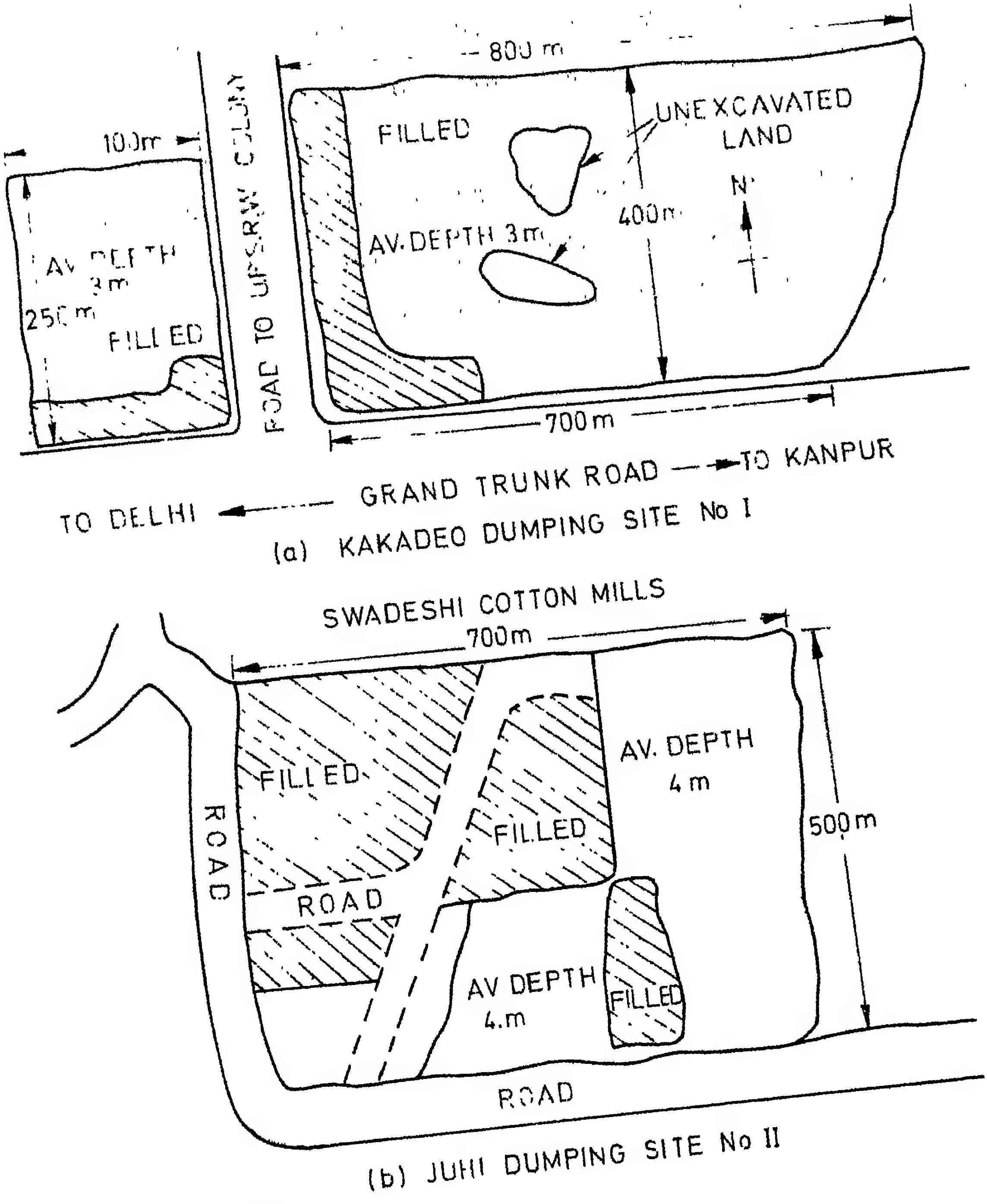
Presently, the refuse is being disposed of by dumping at the two sites, namely, Kakadeo and Juhi. Both the dumping sites belong to Kanpur Nagar Mahapalika. On these dumping sites the refuse is being used for reclaiming the land, simply by dumping the refuse. These sites are situated on the outskirts of the present city. The locations of these dumping sites are shown in Fig.3.4. Kakadeo dumping site is situated on the Grand Trunk Road about 8 km away from the centre of the city. This dumping site is deeply excavated land from where the soil have been used for brick kilns, thus leaving depressions of land from 2 m to 4 m in depth.

Fig. 3.5(a) shows the line sketch of the Kakadeo dumping sites with it's approximate dimensions. On this dumping site out of total volume of .908 million cum only

0.068 million cum has been filled up to-date. It shows that it can accommodate 0.493 million tonne (approx.) of refuse more from the city. Refuse from 54 storage depots of the city is being dumped on this site.

The other one, Juhi dumping site is situated on the southern side of the city on Juhi-Hamirpur Road as shown in Fig. 3.4. This dumping site serves 64 storage depots as mentioned earlier. Here also the refuse is being used for reclaiming the land. This is a natural depression which is being used as a dumping site. Now city has extended beyond this dumping site therefore the value of land also has increased. In mansoon season the water gets stored here in this natural depression and creates nuisance and health hazards to the residents who live nearby this dumping site. Keeping these factors in view it is now proposed by Kanpur Nagar Mahapalika to reclaim this depression as a park. Fig. 3.5(b) shows the land reclaimed at this dumping site. Out of the total volume of 1.4 million cum only 0.49 million cum of volume has been filled with refuse todate. The remaining volume of 0.91 million cum can accommodate 0.535 million tonne (approx.) of refuse from the corresponding 64 storage depots.

The average distance through which the refuse has to be hauled before final dumping varies from 8 to 12 km. But it seems that not much thought have been given to the future expansion potential of the city limits. Even at present



Scale 1cm=80 meters

FIG. 3·5 THE DUMPING SITE LOCATIONS

the city has expanded beyond these dumping grounds. Moreover, the dumping of refuse is not being done under technical supervision, giving adequate attention to the sanitary aspect. Neither compaction of the dumped refuse nor covering it up by earth is practiced properly. These conditions encourage fly breeding, rodent breeding, and malodor, creating health hazards.

CHAPTER IV

4.1. CHARACTERIZATION OF KANPUR REFUSE

The characterization of refuse was carried out during October, 1971 to April, 1972, to asses the present quality and quantity of refuse as well as to predict the quantity at the end of 10 years design period i.e. in the year 1981.

Initially, the whole city area was surveyed to obtain basic information regarding refuse generation areas and collection points. Based on this information representative sample points were selected in each ward, so as to represent all types of activities in that particular ward.

4.2. PHYSICAL AND CHEMICAL ANALYSIS

The sample from any point was obtained by taking four grab samples of 1.0 Kg each from different points on the same refuse heap. The four grab samples were mixed thoroughly. From this mixed mass a one Kg of sample was taken and heated at 100°C over night to measure the loss in weight due to moisture content. From this was calculated the percent moisture content. Now this mixed dried sample was analysed for the different constituted which were then expressed as percentage of the total wet sample weight taken (1.0 Kg). Table 4.1 gives the average analysis values for some of the constituents.

TABLE 4.1

AVERAGE PHYSICAL ANALYSIS OF REFUSE*

Ward No.	Name of Ward	Stones Brick-bats & Mud-Pots	Glass Pieces & Brocken crockery	Sand Silt & Dirt	Metal Pieces	Coal	Paper Rags Woods Leaves & Garbage	Plastic & Leather	Calorific Value Kcal/Kg
1	Nawabganj	20.6	-	22.0	-	3.0	35.4	-	1080
2	Benazabar	21.0	-	18.2	-	10.3	21.3	1.3	....
3	Aryanagar	8.2	-	18.9	-	11.4	25.8	-	1140
4	Gwaltoli	10.6	-	12.7	1.1	-	25.5	-	....
5	Sooterganj	14.4	8.6	22.1	-	15.9	11.1	-	....
6	Civil lines	11.7	-	27.4	-	6.4	42.6	-	1550
7	Patkapur	14.1	0.1	22.5	1.2	18.7	15.3	-	....
8	Feelkhana	16.3	9.4	15.3	-	9.6	32.1	0.2	....
9	Bengalimohal	18.5	5.4	23.8	0.5	2.1	30.5	-	1130
10	Maheswarimohal	15.2	0.6	20.2	-	6.2	31.8	-	....
11	Jernailganj	18.5	1.4	25.0	-	4.4	20.2	-	....
12	Harbansmohal	11.3	-	34.1	0.4	25.4	7.9	1.5	1668
13	Motimohal	17.5	3.3	18.2	-	5.8	20.2	-	....
14	Coolibazar	10.8	-	24.2	1.3	3.5	19.8	2.2	....
15	Zaribchowki	14.3	2.8	32.9	-	2.9	27.3	0.8	1220
16	Laxmipurwa	20.5	1.6	27.2	-	7.6	18.8	-	....
17	Anwarganj	17.5	-	17.4	2.3	2.0	24.4	-	....

Table continued...

TABLE 4.1 Continued

18	Dalelpurwa	18.2	2.7	24.2	0.8	6.3	25.2	0.6	1350
19	Parade	7.0	0.2	14.5	0.2	11.0	43.3	-	....
20	Kernailganj 1	13.0	0.8	17.2	-	14.3	23.5	-	....
21	Kernailganj 2	15.6	3.0	24.8	-	10.4	18.5	1.2	1275
22	Chamanganj	16.0	13.5	18.6	4.1	4.3	20.6	1.6	....
23	Sisamau 1	23.0	-	13.9	-	7.8	25.7	-	....
24	Sisamau 2	9.4	4.6	21.0	1.5	12.2	19.8	0.7	1335
25	Jawaharnagar	17.5	1.3	24.7	-	7.5	27.6	-	....
26	Nehrunagar	12.8	-	24.7	-	6.5	35.2	0.4	....
27	Kaushalpuri	7.4	5.4	27.3	-	6.6	21.5	1.5	1280
28	Darshanpurwa	18.2	-	25.8	2.4	11.5	23.7	-	....
29	Hariharnath Sastrynagar	22.3	2.2	20.5	-	2.3	33.2	-	....
30	Govindnagar	11.5	-	21.0	1.2	14.2	27.4	2.1	1834
31	Juhi-Hamirpur road	16.4	4.2	26.2	-	8.2	21.5	0.3	....
32	Babupurwa 1	7.8	1.8	18.2	-	10.8	31.6	1.2	....
33	Babupurwa 2	15.6	-	20.4	2.0	7.4	24.4	-	1430

* Average of the two samples. Except calorific values, all other are in percentage of wet weight.

The constituents were then again thoroughly mixed, and the mixed dry refuse was then ground to such a size than it can pass through BSS Sieve No. 40. The ground sample was then used for chemical analysis.

A solution of 10 gms of sample in 100 ml distilled water was prepared and after proper stirring, its pH was measured using pH meter*.

10 gms of the above sample was kept in a silica dish and slowly heated in an electric furnace to 700°C for 30 minutes. The remainder was ash and the material lost was the volatile organic matter, which was expressed as percentage.

Carbon was found out by using the New Zealand formula wherein the volatile organic matter percentage was divided by 1.724 to get the carbon percentage.

Total Nitrogen was estimated by using the Kjeldahl's Method and Phosphorous and Potassium were found out by using phosphomolybedic and flame-photometric** methods respectively as given in Methods of Analysis of Refuse Samples in a report by CPHERI [62]. The chemical analysis of refuse is shown in Table 4.2.

For the determination of calorific value of refuse the method given in Municipal Refuse Disposal [12] was adopted.

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* Beckman Expandometic pH meter

** Beckman, DU-2, Flame-Photometer

TABLE 4.2

AVERAGE CHEMICAL ANALYSIS OF REFUSE*

Ward No.	Name of Ward	Moisture	pH	N	P as P_2O_5	K as K_2O	Volatile Organic Matter	C	C/N Ratio
1	Nawabganj	19.2	7.1	0.46	0.72	0.33	23.0	13.3	29.0
2	Benazabar	29.9	6.8	0.50	0.58	0.26	32.9	19.1	38.2
3	Aryanagar	35.7	7.2	0.59	0.60	0.43	34.2	19.8	33.6
4	Gwaltoli	50.1	6.9	0.44	0.51	0.29	30.9	17.9	40.6
5	Sooterganj	28.9	6.8	0.60	0.39	0.22	34.4	20.2	33.4
6	Civil lines	17.7	6.7	0.54	0.57	0.35	39.0	22.6	41.8
7	Patkapur	28.1	7.2	0.55	0.62	0.27	24.5	14.8	26.9
8	Feelkhana	17.1	7.3	0.47	0.42	0.37	41.9	23.6	50.2
9	Bengalimohal	20.2	6.9	0.67	0.54	0.30	24.6	14.3	21.4
10	Maheswarimohal	16.0	7.4	0.51	0.55	0.39	33.4	19.3	37.8
11	Jernailganj	30.5	7.1	0.62	0.43	0.26	31.8	18.4	29.7
12	Harbansmohal	19.6	6.8	0.57	0.46	0.32	43.3	24.8	43.5
13	Motimohal	35.6	7.2	0.54	0.42	0.38	35.5	20.3	37.6
14	Coolibazar	38.2	7.1	0.59	0.62	0.42	37.2	21.6	36.6
15	Zaribchowki	18.6	7.3	0.46	0.54	0.25	29.9	17.4	37.8
16	Laxmipurwa	24.3	7.1	0.39	0.35	0.29	32.2	18.7	48.0
17	Anwarganj	36.4	6.9	0.44	0.67	0.36	26.4	15.3	39.2
18	Dalelpurwa	22.0	7.4	0.58	0.52	0.28	27.5	16.0	27.6

Table continued...

TABLE 4.2 Continued

19	Parade	23.8	7.2	0.57	0.54	0.39	54.3	31.4	55.0
20	Kernailganj 1	31.2	6.8	0.41	0.46	0.38	45.8	26.6	64.8
21	Kernailganj 2	26.5	7.1	0.43	0.53	0.34	31.6	17.7	41.2
22	Chamanganj	21.0	7.3	0.54	0.51	0.22	32.8	19.0	35.2
23	Sisamau 1	29.6	7.1	0.42	0.41	0.27	33.5	19.5	46.5
24	Sisamau 2	30.8	7.3	0.57	0.64	0.52	28.7	16.6	29.2
25	Jawaharnagar	21.4	7.4	0.55	0.42	0.48	35.1	20.4	37.2
26	Nehrunagar	20.2	6.8	0.49	0.65	0.41	29.2	16.9	34.5
27	Kaushalpuri	30.5	6.9	0.56	0.52	0.37	29.4	17.0	30.4
28	Darshanpurwa	18.4	7.0	0.48	0.53	0.44	34.1	19.8	41.0
29	Hariharnath Sastrynagar	19.5	7.3	0.51	0.62	0.49	35.2	20.4	40.0
30	Govindnagar	22.6	7.1	0.53	0.47	0.39	45.8	26.5	50.0
31	Juhi-Hamirpur road	23.2	6.9	0.61	0.54	0.38	30.3	17.6	28.8
32	Babupurwa 1	28.6	6.8	0.55	0.62	0.43	28.5	16.5	30.0
33	Babupurwa 2	30.2	7.2	0.49	0.55	0.34	32.8	19.0	38.8

* Average of two samples. All are in percentage by wet weight.

For finding the calorific value the Oxygen Bomb Calorimeter* was used.

The density of refuse was measured by weighing the truck and the volume occupied by the refuse when it was loaded onto the truck. This procedure was repeated four times on different days at different places and the average value adopted has been used in further calculations. The average density of refuse is given in Appendix IV.

Some of the major characteristics of refuse observed during study have been discussed as follows:

(a) Combustible Matter: The most important factor in incineration of refuse is the quantity of combustible and non-combustible matter in refuse. More the combustible matter in refuse better it will be for incineration. Kanpur refuse contains on an average 34 percent combustible matter. As mentioned in Table 2.8 U.S. cities contains about 65 percent of combustible matter. The high percentage of combustible matter in U.S. cities is due to the use of package materials. Wardwise combustible matter content in refuse produced in Kanpur is shown in Fig. 4.1.

(b) Non-combustible Matter: The percentage of inert or non-combustible matter present in refuse gives the portion that will not undergo any decomposition.

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* Oxygen Bomb Calorimeter, Parr Instrument Company, Inc., Moline, Illinois, U.S.A.

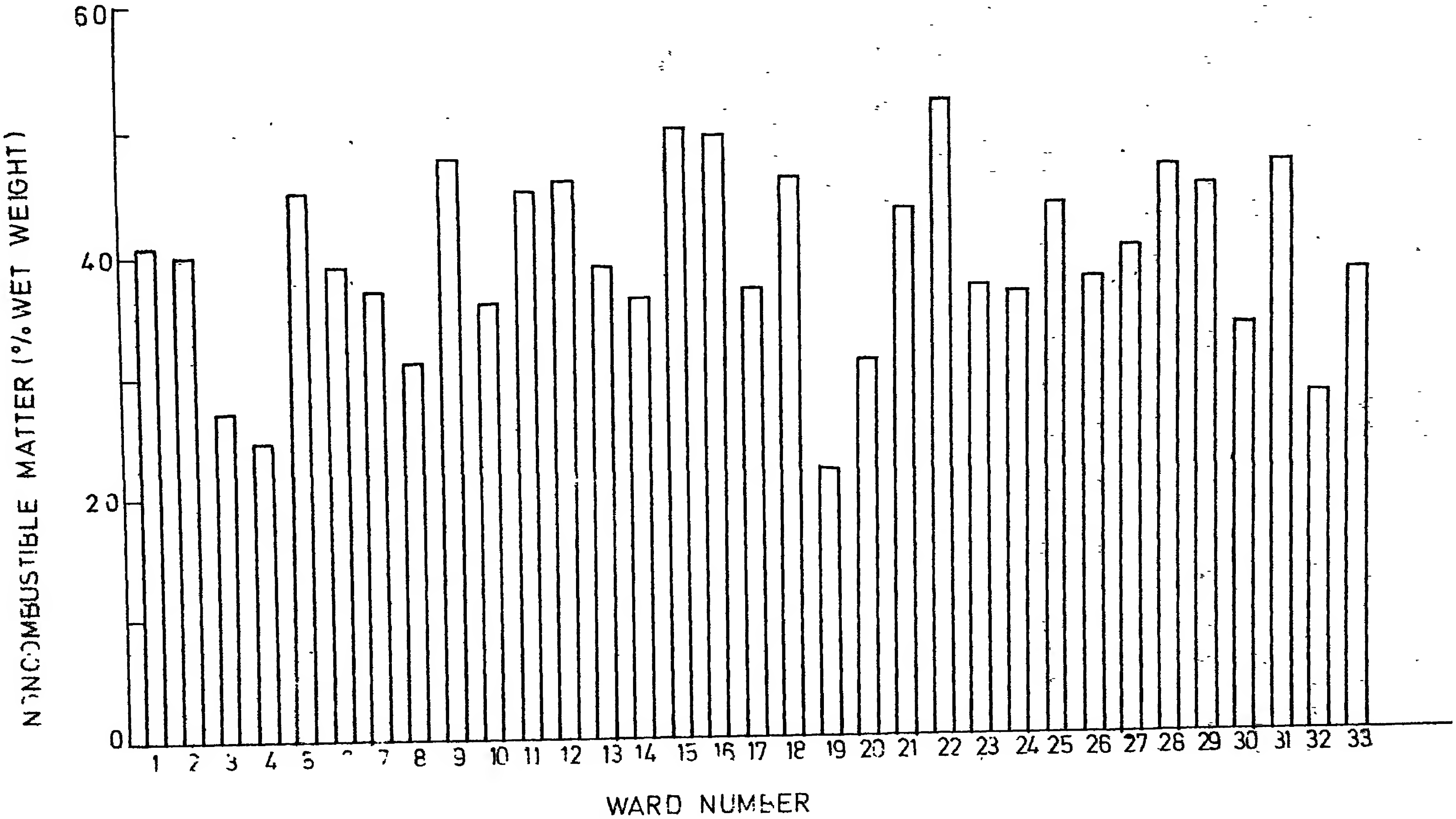
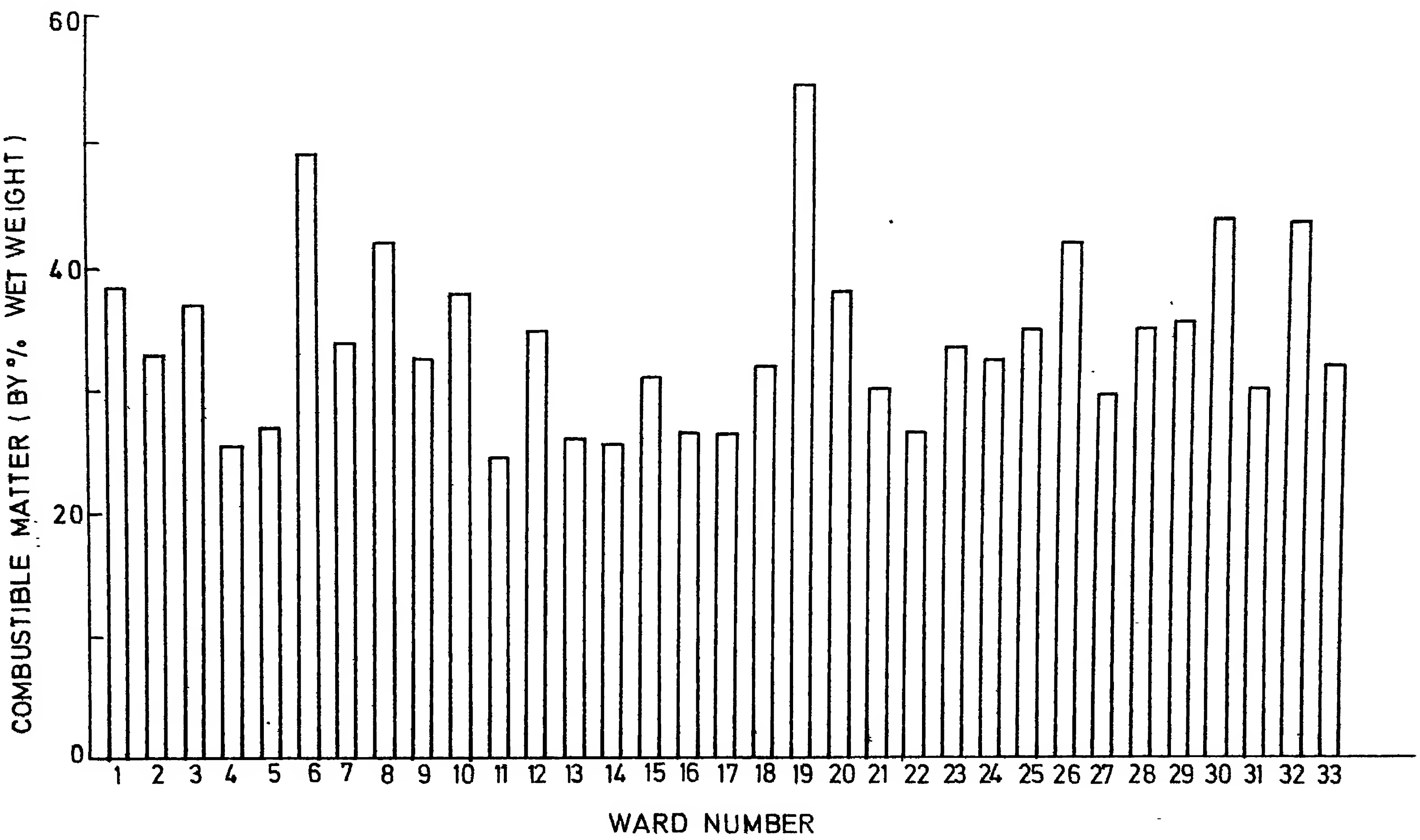


FIG. 4·1 THE NONCOMBUSTIBLE MATTER (% BY WET. WT.) IN EACH WARD

This quantity is useful in calculating the non-degradable portion for the composting process and the likely the quantity of slag in incineration process. Wardwise variation in non-combustible matter content is shown in Fig. 4.2. The average non-combustible matter content of Kanpur refuse is 40 percent, whereas of U.S. cities is about 22.5 percent as mentioned in Table 2.5. The high content of non-combustible matter in refuse is due to high percentage of street dust, demolition wastes etc.

(c) Moisture Content: Moisture content of refuse sample is an important parameter for various disposal methods. For incinerator, the quantity of additional fuel that may have to be provided depends on the moisture content of refuse. In sanitary landfill the amount of compaction that can be done depends on the moisture content of refuse. Also for biological decomposition of organic matter during composting depends on the moisture content of refuse. An average moisture content of Kanpur refuse during the study was found to be 26 percent. The moisture content of refuse varies from ward to ward as shown in Fig. 4.3. As mentioned in Table 2.6 the moisture content of all classes of refuse collected together of U.S. cities varies from 25 to 35 percent. The reason for having higher moisture



FIG· 4·2 COMBUSTIBLE MATTER (% BY WET· WT.) IN EACH WARD

content of Kanpur refuse is due to the improper drainage system in some of the areas in the city.

(d) Volatile Organic Matter: Volatile organic matter plays an important role in selecting a proper disposal method of refuse. Mainly volatile organic matter is present in garbage. Refuse having volatile organic matter with high moisture content may be useful for composting. But with a less moisture content it may be preferable to incinerate the refuse. Kanpur refuse contains about 33 percent of volatile organic matter on an average. Whereas as indicated in Table 2.5 in U.S. cities an apartment refuse contains approximately 59.3 percent of volatile organic matter with 10 percent of moisture content. Due to high moisture content and non-combustible matter the volatile organic matter is comparatively lesser. Wardwise volatile organic matter content is shown in Fig. 4.4.

(e) C/N Ratio: C/N ratio is an important factor for composting. It is desirable to keep C/N ratio in raw mineral from 30 to 40. Somewhat longer composting time is required with high C/N than a low one. Kanpur refuse has C/N ratio on an average 38. Whereas as mentioned by Quartly [17] U.S. cities refuse has 18 to 22. As shown in Fig. 4.5. The C/N ratio of Kanpur refuse varies 21.5 to 65. Having high C/N composting

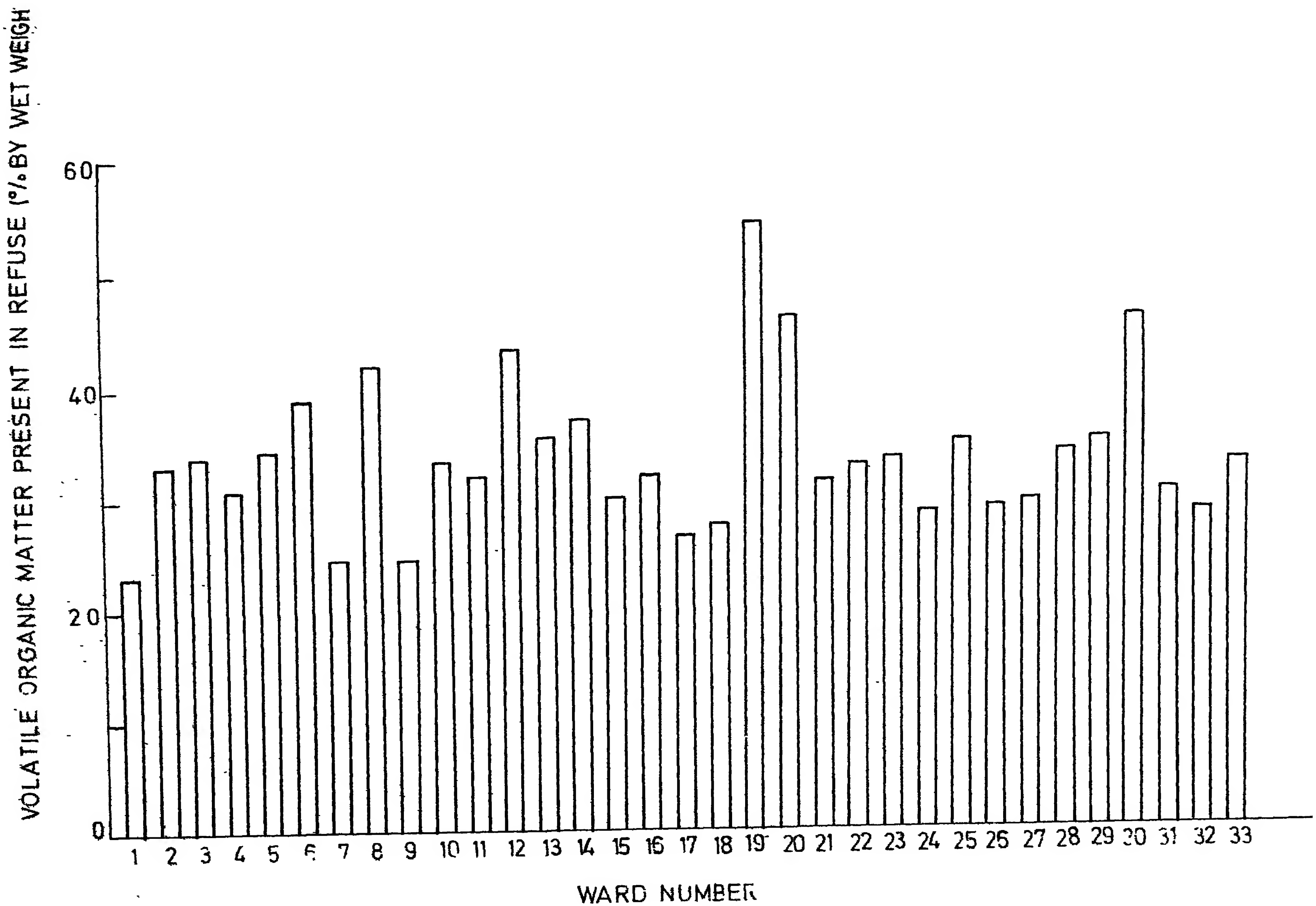


FIG-4-4 VOLATILE ORGANIC MATTER PRESENT IN REFUSE (% BY WET WEIGHT) IN EACH WARD

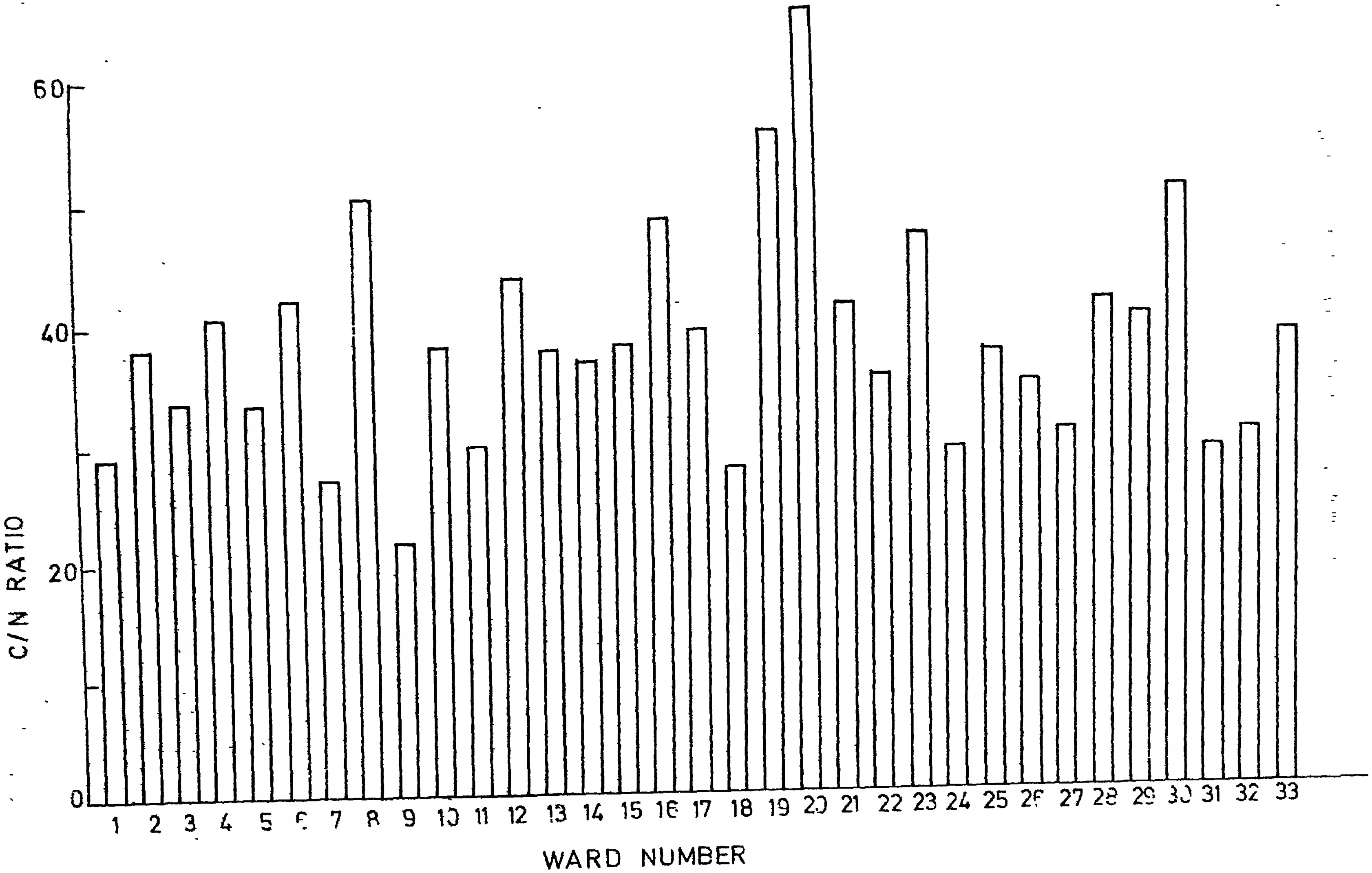


FIG. 4·5 C/N RATIO OF REFUSE OF EACH WARD

has not been considered in this study. Because of longer composting time and other nuisances.

(f) Calorific Value: The refuse to be burnt should have as high a calorific value as possible; as low a moisture content and as high organic matter content as possible. The average calorific value of Kanpur refuse is 1350 Kcal/Kg whereas for Calcutta refuse it is 1500 Kcal/Kg and for U.S. cities about 2728 Kcal/Kg as mentioned in Table 2.8. The reason for having low calorific value of Indian cities refuse is low combustible matter and high moisture content. Calorific value of refuse for some of the wards is shown in Table 4.1.

4.3. KNOWN PER CAPITA REFUSE GENERATION

For the design of future disposal facilities, it is necessary to obtain a correct estimate of the refuse quantities for the city of Kanpur and its trend. For doing this in the best manner it is desirable that the quantities as occurring in the previous years should also be looked into and an estimate be obtained for the future quantity.

4.3.1. Known Per Capita Refuse Generation in the Year 1966

The quantity of refuse generated in the past year were available only for the year 1966 for four months from

the Refuse Disposal Department of Kanpur Nagar Mahapalika. On the basis of these data available, the quantity of refuse generated per capita per day was found as follows.

	Month	Quantity of Refuse Generated in Tonne
1.	September	16,417
2.	October	17,940
3.	November	17,865
4.	December	16,898
	Total	69,120 Tonne

$$\text{Refuse generated per day} = \frac{69,120}{4 \times 30} = 576 \text{ T/day.}$$

The population of the city for the year 1966 was determined by taking the average of the two Census years i.e. for the year 1961 and 1971.

Year	Population
1966	8.76 lakhs
1971	9.44 lakhs
Total	18.20 lakhs

Average = 18.20/2

= 9.1 lakhs.

4.3.2. Known Per Capita Refuse Generation For the Year 1971

As the population of Kanpur is known in the year 1971. Also as the total quantity of refuse for the year 1970-71 is known as given in Table 4.3, the per capita value was worked out which comes out to be 0.674 Kg per capita per day.

4.4. PREDICTION OF THE YEAR 1981 PER CAPITA REFUSE GENERATION

Prediction of the quantities of refuse generation in the year 1981 has been worked out as below.

Estimated refuse generation in 1966 = 0.634 Kg/capita-day

Estimated refuse generation in 1971 = 0.674 Kg/capita-day

The increase in refuse generation in 5 years will be:

$$0.674 - 0.634 = 0.04 \text{ Kg/capita-day}$$

Therefore the increase in 10 years i.e. in 1981 is given by

$$= \frac{0.04 \times 10}{5} = 0.08 \text{ Kg/capita-day}$$

Hence, the total refuse produced per capita per day in 1981

$$= 0.674 + 0.08 = 0.754 \text{ Kg/capita-day}$$

$$\text{or} \quad 0.75 \text{ Kg/capita-day (say)}$$

Refuse generation per capita per day in 1981 will be 0.75 Kg.

4.5. WARDWISE REFUSE GENERATION IN 1981

To determine the wardwise refuse generation in 1981,

TABLE 4.3: QUANTITY OF REFUSE PRODUCED FROM KANPUR CITY IN THE YEAR 1970-71*

Sl. No.	Year	Month	No. of Trips	Quantities of Refuse Produced, Tonne/month
1	1970	April	7,040	19,700
2	"	May	6,020	16,850
3	"	June	6,590	18,450
4	"	July	7,440	20,850
5	"	August	6,320	17,680
6	"	September	6,800	19,100
7	"	October	7,200	20,180
8	"	November	6,765	18,950
9	"	December	7,780	21,800
10	1971	January	6,375	17,860
11	"	February	6,325	17,700
12	"	March	7,040	19,700
			Total	2,28,820 tonne

$$\text{Kg per Capita} = \frac{2{,}28{,}820}{9{,}44{,}000 \times 12 \times 30}$$

$$= 0.674 \text{ Kg/Capita-day}$$

* Data collected from Refuse Disposal Department, Kanpur Nagar Mahapalika, Kanpur.

it is essential to estimate the wardwise population in 1981. Depending on the population of each ward and known refuse generation per capita per day, the total quantities of refuse produced from each ward was determined.

4.5.1. Prediction of Wardwise Population in 1981

For estimating the future population of each ward of Kanpur city, the Ratio Method was used as described by Steel [63]. There are other methods such as Arithmetical Method, Uniform Percentage Rate of Growth Method, Curvilinear Rate of Growth Method and Logistic Method, for predicting population, but in these methods more years of data of wardwise population are required for predicting the future population whereas in Ratio Method only two to four years of data are required.

The advantage of this method of forecasting is based upon the belief that the population of wards or other areas will have a relationship to the population in the whole city. Extrapolation of the trend indicated by the ratios of two years gives a future population for the required year.

In this method the ratio of the population of each ward in the city to the total population of the city has been taken into consideration. From the population in the year 1961 and 1971 of each ward as well as of the city, the ratios were calculated and from the population of the city in 1981,

the ward's population in 1981 have been computed. Fig. 4.6 shows an example for predicting the future population of wards. Kanpur city population is shown in Table 4.4 whereas the predicted population of each ward is shown in Table 4.5.

4.5.2. Prediction of Wardwise Refuse Generation in 1981

For predicting the quantity of refuse produced from each ward in 1981, the predicted population of the ward in 1981 is multiplied by 0.75 Kg/capita-day, which gives the total quantity of refuse in Kg. produced from that particular ward in 1981. The quantity of refuse produced in 1981 from each ward is shown in Table 4.5.

In the developed computer model for determining the cost of transportation of refuse from a ward, the values which have been considered are from Table 4.5 and other data and Computer Program into consideration are given in Appendices II to VII.

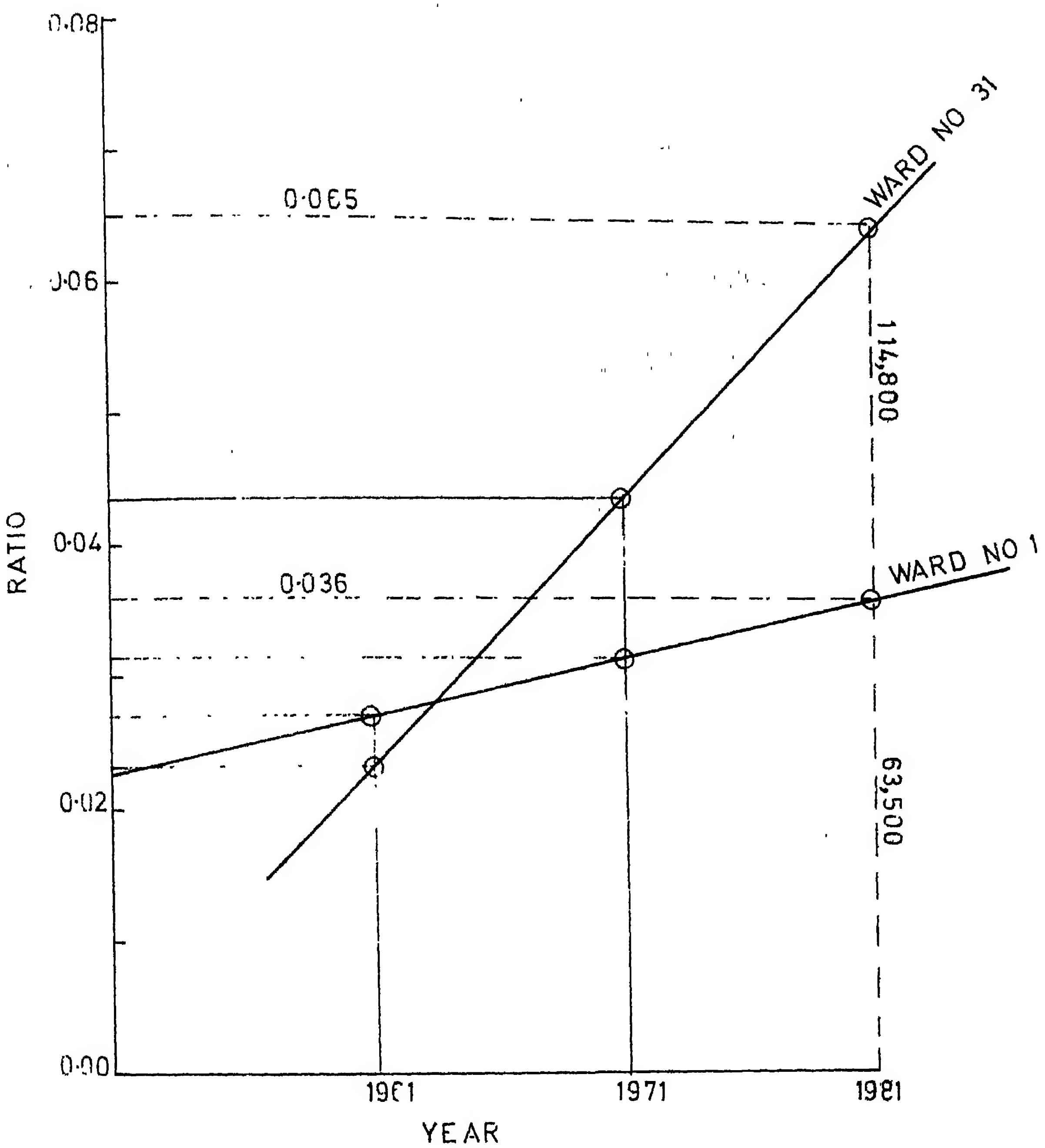


FIG. 4·6 THE PLOT DRAWN BETWEEN YEAR & RATIO

TABLE 4.4: THE PRESENT AND PREDICTED FUTURE POPULATION OF KANPUR CITY*

Sl. No.	Year	Population
1	1961	9.71 lakhs
2	1971	12.74 "
3	1981	17.64 " (Estimated)
4	1991	22.50 " "
5	2001	28.40 " "

* Data collected from Local Self Government Engineering Department, Kanpur from the Master Plan for Kanpur Water Supply Scheme.

TABLE 4.5: PREDICTED QUANTITY OF REFUSE GENERATED FROM EACH WARD IN THE YEAR 1981

Ward No.	Name of Ward	Population in 1961	Population in 1971	Predicted Population in 1981	Predicted Quantity of Refuse generated in 1981 Kg/day
1	Nawabganj	26,455	40,206	63,500	47,450
2	Benazabar	20,182	25,659	33,500	25,000
3	Aryanagar	21,021	25,465	32,600	24,350
4	Gwaltoli	24,484	26,466	29,100	21,700
5	Sooterganj	20,975	23,563	29,220	21,800
6	Civil lines	20,238	20,612	21,200	15,800
7	Patkapur	22,343	24,116	25,600	19,100
8	Feelkhana	22,265	24,011	25,550	19,000
9	Bengalimohal	23,187	24,622	26,600	19,850
10	Maheswarimohal	18,184	18,912	19,400	14,480
11	Jernailganj*	17,169	18,021	19,400	14,480
12	Harbansmohal	24,483	27,156	30,850	23,000
13	Motimohal	22,025	22,290	24,800	18,500
14	Coolibazar	11,010	11,061	11,500	8,600
15	Zaribchowki	24,263	28,053	33,500	25,000
16	Laxmipurwa	22,626	27,895	36,200	27,000
17	Anwarganj	31,329	35,599	42,400	31,600

Table continued...

TABLE 4.5 Continued

18	Dalelpurwa	27,589	32,917	40,600	30,300
19	Parade	27,247	28,678	30,000	22,400
20	Kernailganj 1	25,016	29,450	32,700	24,000
21	Kernailganj 2	26,990	30,952	38,600	24,300
22	Chamanganj	28,583	32,425	38,800	29,000
23	Sisamau 1	27,382	31,465	37,000	46,600
24	Sisamau 2	20,014	22,199	25,500	
25	Jawaharnagar	23,077	27,026	31,700	23,600
26	Nehrunagar	33,863	38,144	49,100	32,900
27	Kaushalpuri	23,773	30,390	41,500	31,700
28	Darshanpurwa*	26,075	29,473	33,500	25,000
29	Hariharnath Sastrinagar	29,525	55,075	88,200	65,800
30	Govindnagar	26,811	45,504	76,700	57,200
31	Juhi-Hamirpur Road	22,744	59,026	1,14,800	85,500
32	Babupurwa 1	29,961	47,206	76,000	56,700
33	Babupurwa 2	27,991	38,895	56,500	42,200

* Wards are not being served by the Kanpur Refuse Disposal Department.

CHAPTER V

5.1. DEVELOPMENT OF MATHEMATICAL MODEL AND A COMPUTER PROGRAM FOR COST OF REFUSE HANDLING AND DISPOSAL

The purpose herein is to develop a mathematical model useful for the cost analysis of transportation and disposal of refuse from a given locality. Several factors have been considered to evaluate the cost model as described below. The main aim of developing the following cost models is to compare the cost of transportation and disposal of refuse firstly by considering refuse transportation cost alone for dumping of refuse and secondly, considering the disposal by incineration.

5.1.1. Mathematical Model for the Cost of Dumping of Refuse From a Locality

The model of refuse transportation cost applies only to the dumping of refuse. The refuse transportation cost Cti from a ward in Rs/week is given by

$$Ci.Xi \qquad \ldots \quad (1)$$

where Ci = The cost of clearing the refuse from a ward i, Rs/trip, and

Xi = The number of trips from a ward i per week.

Ci, in equation (1), can be written as

$$Ci = Di.Co + [Pd + Pl \times Nl]\left[\frac{D_i}{S} + Tl + Tu\right] \qquad \ldots \quad (2)$$

where D_i = Average distance in kilometers from a ward i to the dumping site.

C_o = Operation cost of a vehicle Rs/km

P_d = Pay of a driver Rs/hour

P_l = Pay of a labour Rs/hour

N_l = Number of labour per vehicle

S = Speed of vehicle km/hour

T_l = Time for loading the vehicle with refuse hours/trip

T_u = Time for unloading the refuse from the vehicle hours/trip.

Terms given in equation (2), can again be expressed as follows:

D_i = This is the average distance from a ward i, was determined by measuring the actual distance of the route followed by a vehicle from a depot to the dumping site and thus after finding the distances of all the depots situated in ward i, the average distance was determined by adding up all the route length in km and divided by the number of depots situated in ward i.

C_o, the operation cost of vehicle can be given as

$$C_o = [C_f + C_{mo} + C_m + C_{dv} + C_{iv}] \qquad \ldots \quad (3)$$

where, C_f = Cost of fuel, Rs/km

C_{mo} = Cost of mobile oil, Rs/km

C_m = Maintenance cost of vehicle Rs/km

C_{dv} = Depreciation cost of vehicle Rs/km

In the equation (8), Mu is given by

$$Mu = Lv/Rn \qquad \ldots (9)$$

Tl in equation can be given by

$$Tl = \frac{Rv}{Nl \times Rl} \qquad \ldots (10)$$

where Rv = Capacity of vehicle, M^3

Rl = Refuse loaded by a labour per hour. M^3/lab-hr.

Tu is given by

$$Tu = \frac{Rv}{Nl \times Ru} \qquad \ldots (11)$$

where Ru = Refuse unloaded by a labour per hour M^3/lab-hr.

Now, the equation (2) can be written in a simplified form as:

$$Ci = Di.Co + [Cd + Cl \times Nl]\left[\frac{Di}{S} + \left(\frac{Rv}{Nl \times Rl}\right) + \left(\frac{Rv}{Nl \times Ru}\right)\right] \qquad \ldots (12)$$

Equation (12) gives only the transportation cost per trip from a ward i. Number of trips from a ward depends on the quantity of refuse generated in that ward. Here it is assumed that the refuse generated is collected on the storage depots and from there it is transported.

Let the total quantity of refuse generated from a ward i per week is C_i kg and the density of refuse be ρ.

So, the total volume of refuse Gl generated from ward i per week will be

$$Gl = Gi/\rho \,, \quad M^3/\text{week} \qquad \ldots (13)$$

Hence, Xi in equation (1), can be determined by

$$Xi = \frac{Gl}{Rv} \,, \quad \text{Number of trips per week} \qquad \ldots (14)$$

Hence, finally, the refuse transportation cost from a ward i, Rs/week, is given by:

The transportation cost per trip from the ward i x
The number of trips per week from ward i.

5.1.2. Mathematical Model for the Cost of Incineration of Refuse per Tonne of Refuse Incinerated

5.1.2.1. Mathematical model for refuse transportation cost from a locality to the incinerator

The model for refuse transportation cost Cti from a locality i to the incinerator is given by

$$Cti = Cq/Tc \qquad \ldots (15)$$

where, Cti = Refuse transportation cost from a ward i to the incinerator, Rs/tonne of refuse

Cq = Refuse transportation cost from a ward i to the incinerator, Rs/trip

Tc = Average capacity of a vehicle, tonne/trip.

The value of Cq can be easily determined by substituting the average distance from a ward i to the incinerator in equation (2) as below:

$$Cq = Ddi.Co + [Cd + Cl \times Nl] [\frac{Ddi}{S} + (\frac{Rv}{Nl \times Rl}) + (\frac{Rv}{Nl \times Ru})] \quad \ldots (16)$$

where Ddi = Average distance from a ward i to the incinerator.

There are other costs also, to be considered in finding out the actual cost of incineration of refuse, as follows:

1. Labour Cost: This can be given as

$$Clt = (\frac{1}{Qi} \times Cli) \quad \ldots (17)$$

where Clt = Cost of labour, Rs/tonne of refuse

Qi = Average quantity of refuse handled by a labour to feed in incinerator tonne of refuse/hour

Clt = Cost of labour, Rs/hour

Cli is calculated as follows:

$$Cli = Pli/Whm \quad \ldots (18)$$

where Pli = The pay of a labour per month, working on incinerator Rs/month

Whm = Working hours of a labour per mont hours/month.

Here it may be possible for high rate loading incinerator that some mechanical device may be used for feeding the refuse but however, labours are required to handle the refuse where such type of device is not adopted, and hence, for this the labour cost has been determined as shown in eq. (17).

2. Electricity Charges: For supplying the air to the incinerator by forced draft, blowers are required. A considerable amount of electrical power is consumed by the blowers. To evaluate the electricity charges per tonne of refuse incinerated, the following equation has been developed.

$$Ech = \{[(\frac{Hr}{252,000}.Aq) + Qafuel) - (Qr.Nd)] \times \frac{1}{Qab}.Pb.Cp\} \qquad \ldots (19)$$

where, Ech = Electricity charges, Rs/tonne of refuse incinerated.

Hr = Total heat liberated by refuse Kcal/hour

Aq = Quantity of air required per 252,000 Kcal, tonne of air/252,000 Kcal.

Qafuel = Quantity of air required for auxilary fuel burning in tonne.

Qr = Incinerator loading, tonne of refuse/hour

Nd = Natural draft, tonne of air/tonne of refuse

Qab = Quantity of air produced by a blower, tonne of air/hours

Pb = Power required by a blower, killowatt

Cp = Cost of electric power , Rs/kwh

$$Pc = \frac{Ech}{Qr} \qquad \ldots (20)$$

where, Pc = Cost of electric power per tonne of refuse, Rs/tonne of refuse.

3. Cost of depreciation, interest and maintenance

$$Cto = \frac{Cdi + Cdm + Cii + Cim + Cmi + Cmm}{Qr \times Hw} \quad \ldots (21)$$

where, Cto = Rs/tonne of refuse incinerated.

Cdi = Depreciation cost of incinerator Rs/year.

Cdm = Depreciation cost of electrical and mechanical equipment Rs/year.

Cii = Interest cost of incinerator (civil works) Rs/year.

Cim = Interest cost of electrical and mechanical equipment. Rs/year.

Cmi = Maintenance cost of incinerator (civil works) Rs/year.

Cmm = Maintenance cost of electrical and mechanical equipment Rs/year.

Hw = Working hours of incinerator per year Hours/year.

In the above equation (21), the different terms can be determined as follows:

$$Cdi = Q1 - Q2/Ni \quad \ldots (22)$$

where Q1 = Initial cost of incinerator (civil works), Rs.

Q2 = Salvage value of incinerator (civil works), after Ni years, Rs.

Ni = Useful life of incinerator (civil works), years.

$$Cdm = M1 - M2/Mi \qquad \ldots (23)$$

where, M1 = Initial cost of electrical and mechanical equipments in Rs.

M2 = Salvage value of electrical and mechanical equipments in Rs. after Mi years.

Mi = Useful life of electrical and mechanical equipment in years.

$$Cii = \frac{Ni + 1}{2Ni} \cdot Q1.Ir \qquad \ldots (24)$$

and,

$$Cim = \frac{Mi + 1}{2Mi} \cdot M1 \cdot Ir \qquad \ldots (25)$$

4. Auxilary Fuel Cost: When refuse has got a low calorific value, auxilary fuel is to be used which boosts up the running cost substantially during incineration of refuse. For finding out the cost of auxilary fuel required to incinerate the refuse, following equations have been developed for two different conditions of the incineration, firstly during the steady state burning of refuse in incinerator and secondly during the start-up of the incinerator.

5.1.2.2. Auxilary fuel cost during steady-state burning of the refuse in incinerator

First of all a heat balance equation has been formulated during steady-state burning of refuse in incinerator.

Theoretically the equation can be expressed as follows:

Heat liberated = Heat lost

Heat liberated is given by:

Heat liberated by refuse, Kcal/hour + Heat liberated by auxilary fuel, Kcal/hour.

and heat lost is given by

Heat lost through humid air, Kcal/hour

+ Heat lost through combustible matter present in refuse, Kcal/hour

+ Heat lost through ash (inert matter) Kcal/hour

+ Heat lost through the moisture present in refuse, Kcal/hour

+ Heat lost through walls, Kcal/hour.

Firstly, considering the heat liberated, therefore, heat liberated by refuse Hlr is given by

$$Hlr = Qr \times Hrpt, \text{ Kcal/hour} \quad \ldots (26)$$

where, Hrpt = Heat liberated by per tonne of refuse, Kcal/tonne of refuse

and, Heat liberated by auxilary fuel Hlf is given by

$$Hlf = Qf \times Hf \times Qr, \text{ Kcal/hour} \quad \ldots (27)$$

where, Qf = Quantity of auxilary fuel required in tonne to burn one tonne of refuse.

Hf = Calorific value of auxilary fuel, Kcal/tonne of fuel.

Now, considering the following various factors through which the heat is lost.

1. Heat lost through humid air: In the incineration of refuse a required quantity of air is to be supplied for the efficient combustion. Actually air is supplied to supply the oxygen to enhance and support the combustion. During the process of incineration humid air also gets heated up and passes through the stack. In this way, some heat is lost through the humid air, Here it is assumed that whatsoever the quantity of air is being put in incinerator the same quantity after combustion is coming out. Heat lost through the humid air is given by

$$\text{Hair} = [\text{Qair}.\text{Qr}(\text{Tf} - \text{To})\{\text{Cpa} + \text{Cv}.\eta\}] \quad \ldots (28)$$

where, Hair = Heat lost through humid air in Kcal/hour.

Qair = Quantity of air required to burn one tonne of refuse, tonne of air/tonne of refuse.

$$\text{Qair} = (\text{Qair for refuse} + \text{Qafuel}) \quad \ldots (29)$$

where, Qafuel = Quantity of air required for auxilary fuel

$$\text{Qair is given by: } \frac{\text{Hrpt} \times \text{Aq}}{252{,}000} \quad \ldots (30)$$

where, Tf = Steady state flame temperature inside the incinerator, °C

To = Surrounding atmospheric temperature out-side the incinerator, °C

Cpa = Specific heat of air, Kcal/tonne-°C

Cv = Specific heat of water vapour, Kcal/tonne-°C

η = Humidity in air, tonne/tonne of air.

Air required for burning of auxilary fuel:

Some quantity of air is also required in burning of auxilary fuel and it is given by

$$Qafuel = Hf..0033.Qf/2520 \qquad \ldots (31)$$

where, .0033 tonne of air is required per 2520 Kcal of auxilary fuel.

The value of Qafuel obtained from equation (31) can be substituted in the equation (19).

2. Heat lost through combustible matter present in refuse:
Some of the heat is lost while burning the combustible matter present in refuse. It has been assumed that combustible matter after burning converts into gases and pass out through the stack as exhaust gases. The specific heat of this exhaust gas is assumed to be the same as that of the air. Heat lost through combustible matter is given by

$$Hgas = Qr.Combus.Cpq.(Tf - Tu) \qquad \ldots (32)$$

where, Hgas = Heat lost through the combustible matter present in the refuse, in the form of gas. Kcal/hour.

Combus = Percent of combustible matter present in refuse.

3. Heat lost through inert matter present in refuse: During the process of burning of refuse heat is also lost through ash and inert matter present in refuse. It is given by

$$Hash = Qr.Finert.Cpi.(Tf - To) \qquad \ldots (33)$$

where, Hash = Heat lost through ash and inert matter present in refuse, Kcal/hour

Finert = Inert matter present in refuse in percentage

Cpi = Specific heat of ash or inert matter Kcal/tonne-°C.

4. Heat lost through the moisture present in refuse: A considerable amount of heat is lost during incineration of refuse containing a quite high amount of moisture. Because some of the heat is taken by the moisture to evaporate and thus heat loss takes place. This heat lost can be determined by the following formula:

$$Hlm = Qr[Qm\{Cw(100 - To) + \lambda + (Tf - 100)Cv\}] \qquad \ldots (34)$$

where, Hlm = Heat lost through the moisture present in refuse Kcal/hour

Qm = Quantity of moisture present in refuse, tonne of moisture/tonne of refuse.

Cw = Specific heat of water, Kcal/tonne-°C

λ = Latent heat of vapour, Kcal/tonne.

5. Heat lost through the walls of incinerator: When refuse is burnt in the incinerator some of the heat is lost through the walls due to the temperature gradient. To conserve the heat in the furnace, firebrick lining is provided inside the furnace of incinerator, but still a considerable amount of heat is lost through furnace walls, and it can be determined by the given formula

$$Hlw = [h.A.(Tf - To)] \qquad \ldots (35)$$

where, Hlw = Heat lost through walls, Kcal/hour

h = Heat transfer co-efficient, Kcal/M^2-hr-°C

h can be given by

$$h = k/w \qquad \ldots (36)$$

where, K = Thermal conductivity of wall material, Kcal/ M-hr-°C

w = Thickness of furnace wall in meters

A = Area of walls of furnace, M^2.

Now, by having formulated the

Heat liberated = Heat lost

as in the above written equations, the heat balance equation can be written as

$$Qr.Hrpt + Qf.Hf.Qr = Qair.Qr(Tf - To)\ \{Cpa + Cv.\eta\}$$
$$+ Qr.Combus.Cpa(Tf - To)$$
$$+ Qr.Finert.Cpi(Tf - To)$$
$$+ Qr[Qm\{Cw(100 - To) + \lambda + (Tf - 100)Cv\}]$$
$$+ h.A.(Tf - To) \qquad \ldots (37)$$

In the above heat balance equation (37), the unknown is Qf, and can be determined as follow:

$$Qf = [[Qair.Qr.(Tf - To)\{Cpa + Cv.\eta\} + \{Qr.Combus.Cpa.(Tf - To)\} + \{Qr.Finert.Cpi(Tf - To)\} + Qr[Qm\{Cw(100 - To) + \lambda + (Tf - 100)Cv\}] + h.A.(Tf - To)]] - Qr.Hrpt/Hf.Qr \qquad \ldots (38)$$

By having known the cost of auxilary fuel as Caf, Rs/tonne of auxilary fuel, the total cost of auxilary fuel required in steady-state burning of the incinerator can be given by

$$Coa = Qf.Caf \qquad \ldots (39)$$

where, Coa = Total cost of auxilary fuel required in steady state burning of refuse, Rs/tonne of refuse.

By adding up the values determined from the equations (15), (17), (19), (20) and (39) the total cost of incineration of refuse per tonne of refuse can be determined and it can be given as follow:

$$Ctt = Cti + Clt + Ech + Cto + Coa \quad \ldots (40)$$

where, Ctt = Cost of incineration of refuse per tonne of refuse, Rs/tonne of refuse incinerated.

5.1.2.3. Cost of auxilary fuel required during the Start-up of incinerator

The second most important factor in calculating the cost of auxilary fuel required is the quantity of auxilary fuel required in the beginning of the incinerator that is during the start-up of the incinerator. In the unsteady state also the quantity of auxilary fuel required depends on the same losses as have been described in section 5.1.2.1., except for few changes which have been mentioned below: Here again, following the same relationship, that is

Heat liberated = Heat lost.

In the initial stage it is assumed that whatsoever the heat is being liberated, it is only due to auxilary fuel, because refuse contains some amount of moisture and it is not very well known that when it will start liberating the heat. Moreover, by this assumption, though the quantity of auxilary fuel in start-up required will be more, but it is desirable to add more quantity of auxilary fuel in the beginning for the efficient working of incinerator.

The heat liberated by auxilary fuel is given by:

$$Fr.Hf \qquad \ldots (41)$$

where, Fr = Quantity of auxilary fuel, being supplied in the incinerator, tonne.

Hf = Heat value of auxilary fuel, Kcal/tonne of auxilary fuel.

Now, the total heat lost is given by:

Heat absorbed by the incinerator furnace walls,

+ Heat lost through the furnace walls

+ Heat lost through humid air

+ Heat lost through combustible matter present in refuse

+ Heat lost through ashes or inert matter present in refuse

+ Heat lost through moisture present in refuse.

1. Heat absorbed by the incinerator furnace walls: During the start-up of the incinerator, the furnace walls get heated up by absorbing the heat generated inside the furnace because previously walls were cool and when process of incineration starts wall get heat from the inside burning material may be auxilary fuel or refuse or both, and thus quite a lot of heat is absorbed by furnace walls. This heat absorbed by the walls can be written as

$$Hinc = Winc.Cpinc.[(\frac{Tf + To}{2}) - To] \qquad \ldots (42)$$

where, $Hinc$ = Heat absorbed by the furnace walls in Kcal

$Winc$ = Weight of the furnace walls in tonne

$Cpinc$ = Heat capacity of wall material Kcal/tonne-°C

Tf = Final temperature inside the furnace, °C

To = Surrounding temperature, °C.

Here it is assumed in equation (42) that the temperature gradient follows a linear relationship, which is theoretically not true, but by assuming that the final temperature Tf reaches suddenly from To, and thus considering an average value as $(\frac{Tf + To}{2})$ for the higher side temperature of walls.

2. Heat lost through furnace walls: There will be a heat loss through furnace walls also, as mentioned in section 5.1.2.1. by equation (35). But here, in this case the final temperature is taken as the average $(\frac{Tf + To}{2})$, and also a time factor T is taken into consideration to reach steady state condition. The expression for the heat lost through walls is given by

$$Hlinc = Htc.A.[(\frac{Tf + To}{2}) - To] \times T \qquad \ldots (43)$$

where, $Hlinc$ = Heat lost through walls in Kcal

Htc = Heat transfer coefficient of wall material Kcal/hr-M^2-°C

A = Area of furnace walls, M^2

T = Time taken into consideration from start-up of the incinerator to reach the steady state condition, hour.

3. Heat lost through humid air: In the initial stage also some of the heat will be lost through the humid air, supplied for the combustion of refuse. The heat lost through humid air is given by:

$$Hair = [Qair.Qr.T.(Tf - To)\{Cpa + Cv.\eta\}] \quad \ldots (44)$$

where, Hair = Heat lost through humid air, Kcal

Qair = Quantity of air required in tonnes to burn one tonne of refuse, ~~tonne of~~ air/tonne of refuse

Qr = Incinerator loading, tonne/hour

Cpa = Specific heat of air, Kcal/tonne-°C

Cv = Specific heat of water vapour, Kcal/tonne-°C

η = Humidity present in air tonne/tonne of air.

4. Heat lost through combustible matter present in refuse: It is given by:

$$Hgas = Qr.Combus.Cpa.(Tf - To).T \quad \ldots (45)$$

where, Hgas = Heat lost through the combustible matter present in refuse, Kcal

Combus = Percentage of combustible matter present in refuse.

5. Heat lost through inert matter present in refuse: It is given by:

$$Hash = Qr.Finert.Cpi.(Tf - To).T \qquad ... (46)$$

where, Hash = Heat lost through inert matter present in refuse, Kcal

Finert = Percentage of inert matter present in refuse

Cpi = Specific heat of inert matter (ash), Kcal/tonne-°C.

6. Heat lost through moisture present in refuse: During unsteady state burning of refuse quite a good amount of heat will be lost through the moisture present in refuse. The expression for this heat lost is given by:

$$Hlm = Qr[Qm\{Cw(100 - To) + \lambda + (Tf = 100)Cv\}].T \qquad ..(47)$$

where, Hlm = Heat lost through the moisture present in refuse, Kcal

Qm = Quantity of moisture present in refuse tonne of moisture/tonne of refuse

Cw = Specific heat of water, Kcal/tonne-°C

λ = Latent heat of water vapour, Kcal/tonne

Cv = Specific heat of water vapour, Kcal/tonne-°C

Now, by equating the above equation for,

Heat liberated = Heat lost

$$Fr \times Hf = [Hinc+Hlinc+Hair+Hgas+Hash+Hlm] \qquad ... (48)$$

In the above equation (48) except Fr, all other quantities are known. Therefore to determine Fr, it can be written as

$$Fr = [Hinc+Hlinc+Hair+Hgas+Hash+Hlm]/Hf \qquad \ldots (49)$$

Now, if the cost of auxilary fuel be Caf, Rs/tonne, the total cost of auxilary fuel required in unsteady state will be

$$Coa = Fr \times Caf \qquad \ldots (50)$$

where, Coa = Total cost of auxilary fuel required in unsteady state condition, Rs.

In the unsteady state burnihg, the main question comes in, is that for how long will it take to reach the steady state condition in incinerator. For this reason a parameter T (time) is also taken into consideration in above equations. Because except Hinc, all the other losses are dependent on time. So, by considering a suitable period for bringing up the incinerator to steady state from unsteady state, the auxilary fuel rate can be determined as follows:

$$Frate = Fr/Time \qquad \ldots (51)$$

where, Frate = Auxilary fuel rate during unsteady state burning in incinerator, tonne/hour.

7. Quantity of air required to burn auxilary fuel in unsteady state condition: It can be given by:

$$Qafuel = Hf \times 0.0033 \times Fr/2520 \qquad \ldots (52)$$

where, Qafuel = Quantity of air required to burn auxilary fuel, tonne

Hf = Calorific value of auxilary fuel, Kcal/tonne

Fr = Quantity of auxilary fuel required in tonne.

The quantity of air which is determined by equation (52), has been added in equation (44) in the term Qair to determine the heat lost through the humid air.

5.1.3. Computer Program for Cost of Refuse Handling and Disposal

A computer program has been developed for the calculation required in section 5.1.1., 5.1.2., 5.1.2.2.. Computer program developed, is shown in appendices.

CHAPTER VI

RESULTS

6.1. APPLICATION OF THE MATHEMATICAL MODEL TO KANPUR DATA

The mathematical models developed in chapter V for determining the cost of refuse transportation and the cost of incineration were used in computing the cost analyses using Kanpur data.

6.1.1. Dumping of Refuse

Present refuse dumping sites were considered in evaluating the refuse transportation cost. At present out of 36 wards only 31 wards are being served by the refuse disposal department. Actually in the cost analyses studies only 30 wards have been considered because ward nos. 32 and 33 have got only one refuse storage depot. Where as ward nos. 11, 28, 34, 45 and 36 are not served by the refuse disposal department. In this way the total number of wards, being served comes out to be 30 only.

The quantity of refuse generated considered was of the year 1981. Since the quantity of refuse generated depends on the population, so far determining the quantity of refuse generated in each ward the population of the particular ward in the year 1981 was considered as described

in the chapter IV. As for as the other data are concerned, they are considered on the basis of the present situation as given in Appendices II to V.

6.1.2. Incineration of Refuse

In the cost analysis of refuse incineration, four incinerator sites were considered in the study. These four incinerator sites are shown in Fig. 6.1. Two incinerator sites Nos. 1 and 2 were chosen on the present dumping sites whereas other two incinerator sites nos. 3 and 4 were chosen on the bank of river Ganges. For the refuse disposal by incinerator, four incinerator of different capacities viz. 50, 100, 200 and 250 T/day were designed and taken into consideration.

For each of these incinerator on each site, the cost analysis was carried out, and a comparative cost study was done. In finding out the cost of refuse incineration the data given in Appendices II to V were considered.

6.2. RESULTS OF COST OF REFUSE DUMPING

The refuse transportation cost computed is shown in Table 6.1. The corresponding refuse transportation cost per tonne of refuse is also shown in the same table.

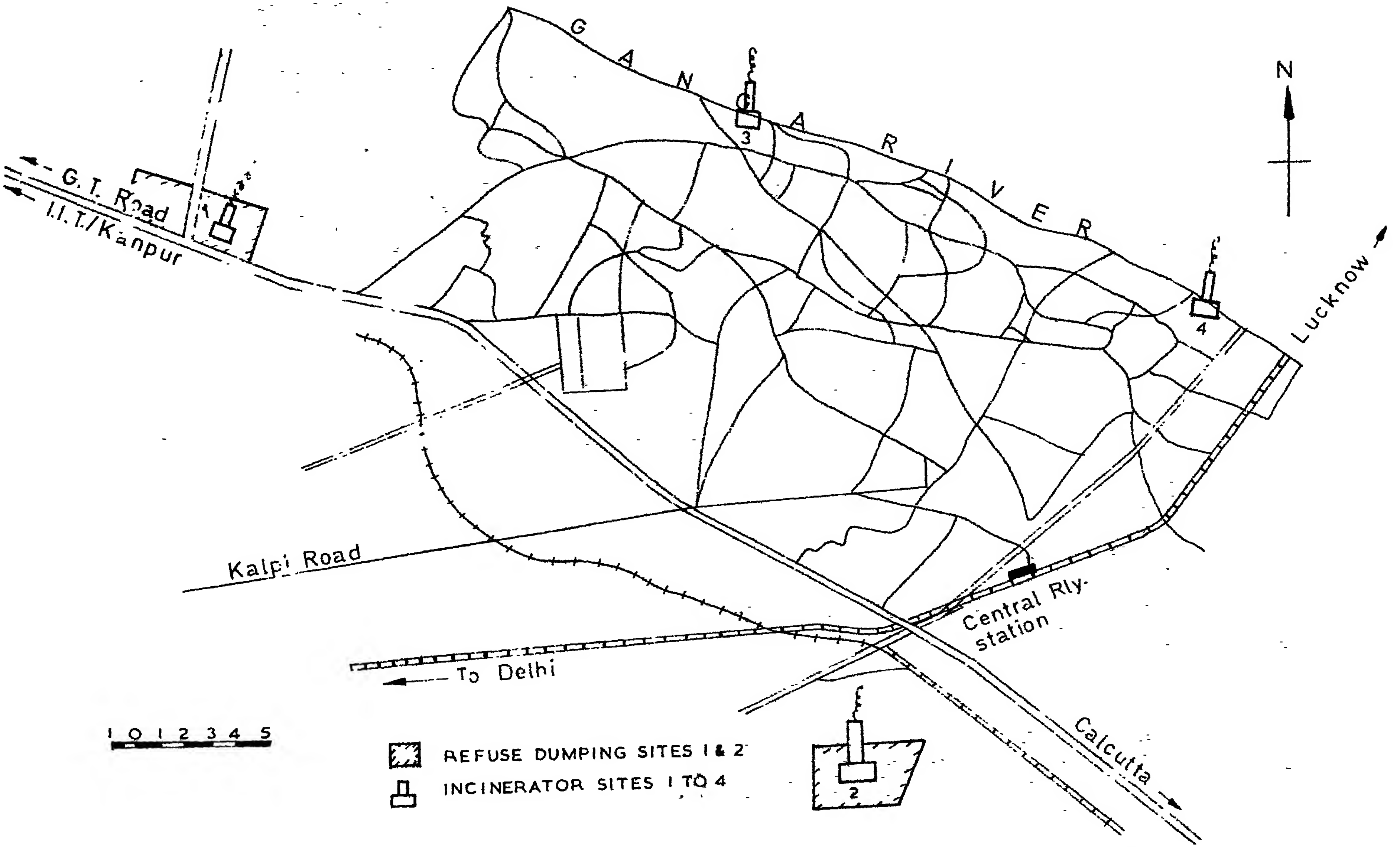


FIG. 6·1 LOCATION OF REFUSE DUMPING AND INCINERATOR SITES

TABLE 6.1: COMPUTED REFUSE TRANSPORTATION COSTS FOR DUMPING FROM WARDS

Ward No.	Refuse transportation cost from wards, Rs/week		Refuse transportation cost from wards, Rs/tonne	
	For Dumping Site No. 1	For Dumping Site No. 2	For Dumping Site No. 1	For Dumping Site No. 2
1	1252.03	1674.39	3.774	5.048
2	645.92	798.75	3.965	4.570
3	662.86	741.57	3.893	4.356
4	672.80	617.92	4.434	4.073
5	672.06	611.18	4.409	4.010
6	507.25	416.91	4.592	3.774
7	422.07	510.28	3.160	3.821
8	653.09	522.88	4.890	3.915
9	678.74	552.14	4.890	3.978
10	479.20	390.04	4.733	3.852
12	806.68	579.07	5.016	3.601
13	685.46	494.25	5.299	3.821
14	280.82	208.96	4.670	3.475
15	711.89	579.94	4.073	3.318
16	831.19	611.49	4.403	3.239
17	906.78	726.10	4.104	3.286
18	962.76	756.20	4.544	3.569
19	716.67	583.67	4.576	3.727
20	688.69	667.58	4.104	3.978

Table continued...

TABLE 6.1 Continued

21	682.58	666.64	4.041	3.947
22	835.36	790.72	4.120	3.900
23	1316.71	1285.97	4.041	3.947
24	646.07	621.16	3.915	3.764
25	857.26	842.79	3.727	3.664
26	825.99	825.99	3.727	3.727
27	1678.34	1685.58	3.648	3.664
29	1955.86	1138.22	4.890	2.846
30	3301.17	1763.64	5.504	2.940
31	1951.23	1153.21	4.922	2.909
32 & 33	1415.12	672.69	4.796	2.280

6.3. RESULTS OF COST OF REFUSE INCINERATION

The cost of incineration of refuse for incinerators of different capacities for different sites are shown in Table 6.2, 6.3, 6.4 and 6.5.

For the above results of sections 6.2 and 6.3 the corresponding figures are drawn to show the cost variation with other factors. The figures shown are from Fig. no. 6.2 to 6.12.

6.4. AUXILARY FUEL COSTS

The costs of auxilary fuel required to burn the refuse of various moisture content at different calorific values have been calculated for steady-state burning and during start-up of incinerator.

6.4.1. Auxilary Fuel Costs at Steady-State Burning

Refuse having different calorific values e.g. 1400, 1200, 1000 Kcal/Kg with different combustible matter content as 40, 30, and 20 percent respectively have been considered to find out the auxilary fuel cost of various moisture content of refuse as 30, 40, 50 and 60 percent. The auxilary fuel costs calculated for 100 and 200 T/day incinerator capacities. Auxilary fuel costs for 100 T/day incinerator capacity is shown in Table 6.6. The corresponding relationship between the above parameters is shown in Fig. 6.13.

TABLE 6.2. COMPUTED COST OF INCINERATION OF REFUSE,

(INCINERATOR CAPACITY = 50 TONNE/DAY)

Ward No.	Cost of incineration of refuse, Rs/tonne of refuse incinerated			
	For Incinerator Site No.1	For Incinerator Site No. 2	For Incinerator Site No. 3	For Incinerator Site No.4
1	9.759	11.033	8.627	10.074
2	9.681	10.555	8.643	9.838
3	9.879	10.341	8.684	9.523
4	10.420	10.058	8.753	9.398
5	10.395	9.995	8.800	9.335
6	10.577	9.759	9.398	8.649
7	9.146	9.806	9.627	8.674
8	10.876	9.901	9.712	8.706
9	10.876	9.964	9.806	8.737
10	10.719	9.838	9.712	8.894
12	11.002	9.586	9.964	8.863
13	11.285	9.806	10.231	8.910
14	10.656	9.460	9.939	9.114
15	10.058	9.303	9.838	9.492
16	10.388	9.225	9.932	10.687
17	10.089	9.272	9.838	9.766
18	10.530	9.555	9.649	9.177
19	10.561	9.712	9.564	8.957
20	10.089	9.964	9.209	9.225

Table continued...

TABLE 6.2 Continued

21	10.027	9.932	9.303	9.354
22	10.105	9.885	9.429	9.539
23	10.027	9.932	9.272	9.555
24	9.901	9.750	9.309	9.775
25	9.712	9.649	9.256	9.932
26	9.712	9.712	9.460	10.341
27	9.633	9.649	9.964	10.781
29	10.876	8.831	10.876	10.498
30	11.489	8.926	11.064	10.687
31	10.907	8.894	10.656	10.341
32 & 33	10.781	8.265	10.561	10.152

TABLE 6.3: COMPUTED COST OF INCINERATION OF REFUSE

(INCINERATOR CAPACITY = 100 TONNE/DAY)

Ward No.	Cost of incineration of refuse, Rs/tonne of refuse incinerated			
	For Incinerator Site No.1	For Incinerator Site No. 2	For Incinerator Site No. 3	For Incinerator Site No.4
1	8.821	10.095	7.689	9.136
2	8.743	9.617	7.705	8.900
3	8.941	9.403	7.745	8.585
4	9.482	9.120	7.815	8.459
5	9.456	9.057	7.862	8.397
6	9.639	8.821	8.459	7.711
7	8.208	8.868	8.689	7.736
8	9.938	8.963	8.774	7.768
9	9.938	9.026	8.868	7.799
10	9.780	8.900	8.774	7.956
12	10.064	8.648	9.026	7.925
13	10.347	8.868	9.293	7.972
14	9.718	8.522	9.000	8.176
15	9.120	8.365	8.900	8.554
16	9.450	8.286	8.994	9.749
17	9.151	8.334	8.900	8.827
18	9.592	8.617	8.711	8.239
19	9.623	8.774	8.626	8.019
20	9.151	9.026	8.271	8.286

Table continued...

TABLE 6.3 Continued

21	9.088	8.994	8.365	8.415
22	9.167	8.947	8.491	8.601
23	9.088	8.994	8.334	8.617
24	8.963	8.812	8.371	8.837
25	8.774	8.711	8.318	8.994
26	8.774	8.774	8.522	9.403
27	8.695	8.711	9.026	9.843
29	9.938	7.893	9.938	9.560
30	10.551	7.988	10.126	9.749
31	9.969	7.956	9.718	9.403
32 & 33	9.843	7.327	9.623	9.214

TABLE 6.4: COMPUTED COST OF INCINERATION OF REFUSE

(INCINERATOR CAPACITY = 200 TONNE/DAY)

Ward No.	Cost of incineration of refuse, Rs/tonne of refuse incinerated			
	For Incinerator Site No.1	For Incinerator Site No. 2	For Incinerator Site No. 3	For Incinerator Site No.4
1	8.403	9.677	7.271	8.718
2	8.325	9.199	7.287	8.482
3	8.523	8.985	7.328	8.167
4	9.064	8.702	7.397	8.042
5	9.039	8.639	7.444	7.979
6	9.221	8.403	8.042	7.293
7	7.790	8.450	8.271	7.318
8	9.520	8.545	8.356	7.350
9	9.520	8.608	8.450	7.381
10	9.363	8.482	8.356	7.538
12	9.646	8.230	8.608	7.507
13	9.929	8.450	8.875	7.554
14	9.300	8.104	8.583	7.758
15	8.702	7.947	8.482	8.136
16	9.032	7.869	8.576	9.331
17	8.734	7.916	8.482	8.410
18	9.174	8.199	8.293	7.821
19	9.205	8.356	8.208	7.601
20	8.734	8.608	7.853	7.869

Table continued...

TABLE 6.4 Continued

21	8.671	8.576	7.947	7.998
22	8.749	8.529	8.073	8.183
23	8.671	8.576	7.916	7.199
24	8.545	8.394	7.953	8.419
25	8.356	8.293	7.900	8.576
26	8.356	8.356	8.104	8.985
27	8.277	8.293	8.608	9.425
29	9.520	7.475	9.520	9.142
30	10.133	7.570	9.709	9.331
31	9.551	7.538	9.300	8.985
32 & 33	9.425	6.909	9.205	8.796

TABLE 6.5: COMPUTED COST OF INCINERATION OF REFUSE

(INCINERATOR CAPACITY = 250 TONNE/DAY)

Ward No.	Cost of incineration of refuse, Rs/tonne of refuse incinerated. For Incinerator Site No.1	For Incinerator Site No. 2	For Incinerator Site No. 3	For Incinerator Site No.4
1	8.333	9.607	7.201	8.648
2	8.255	9.129	7.217	8.412
3	8.453	8.915	7.258	8.097
4	8.994	8.632	7.327	7.972
5	8.969	8.569	7.374	7.909
6	9.151	8.333	7.972	7.223
7	7.720	8.380	8.201	7.248
8	9.450	8.475	8.286	7.280
9	9.450	8.538	8.380	7.311
10	9.292	8.412	8.286	7.468
12	9.576	8.160	8.538	7.437
13	9.859	8.380	8.805	7.484
14	9.230	8.034	8.512	7.688
15	8.632	7.877	8.412	8.066
16	8.962	7.799	8.506	9.261
17	8.663	7.846	8.412	8.340
18	9.104	8.129	8.223	7.751
19	9.135	8.286	8.138	7.531
20	8.663	8.538	7.783	7.799

Table continued...

TABLE 6.5 Continued

21	8.601	8.506	7.877	7.927
22	8.679	8.459	8.003	8.113
23	8.601	8.506	7.846	8.129
24	8.475	8.324	7.883	8.349
25	8.286	8.223	7.830	8.506
26	8.286	8.286	8.034	8.915
27	8.207	8.223	8.538	9.355
29	9.450	7.405	9.450	9.072
30	10.063	7.500	9.638	9.261
31	9.481	7.468	9.230	8.915
32 & 33	9.355	6.839	9.135	8.726

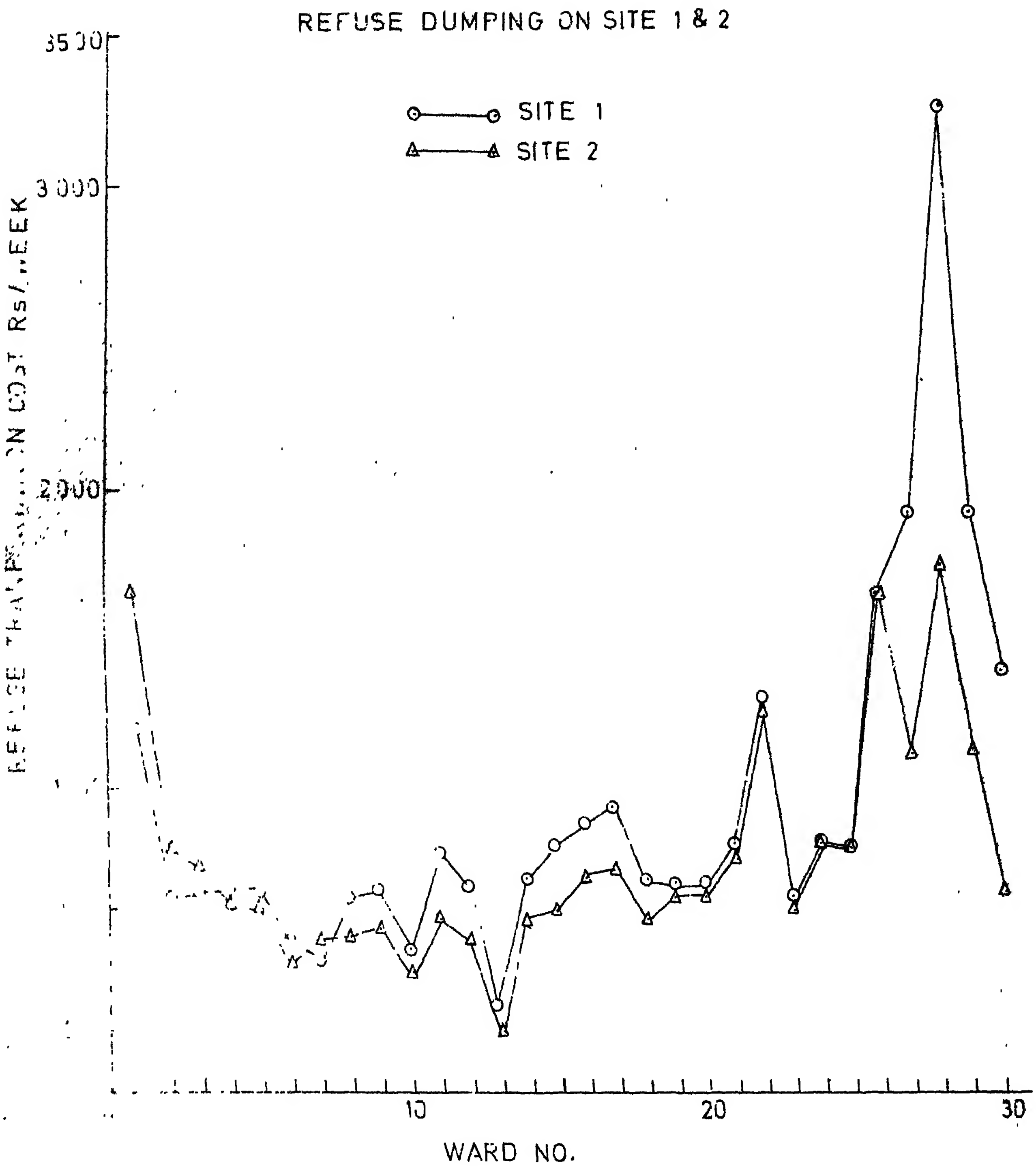


FIG. 6.2 VARIATION IN REFUSE TRANSPORTATION COST AND WARD NOS

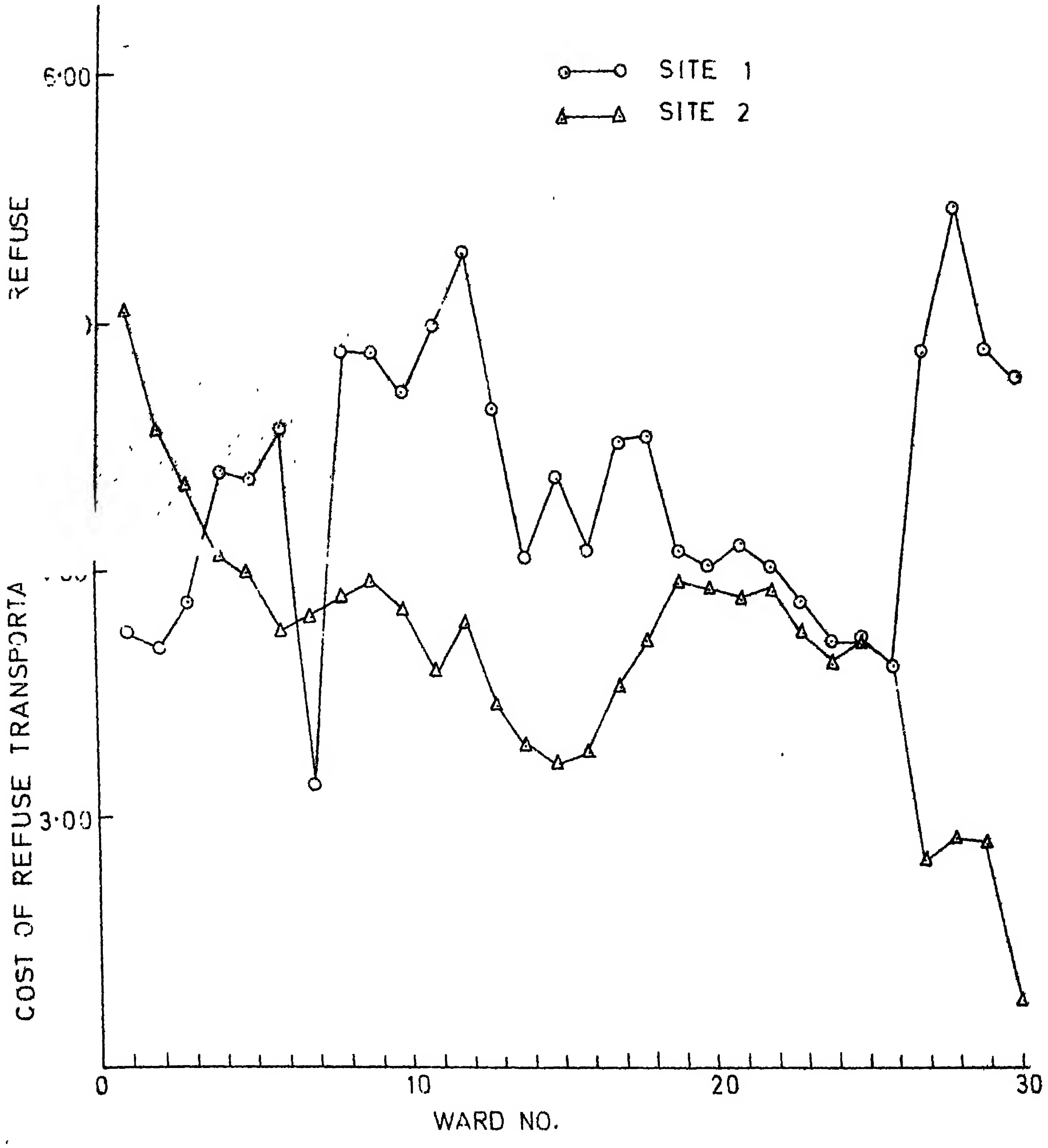


FIG 6·3 VARIATION IN COST OF REFUSE TRANSPORTATION AND WARD NOS.

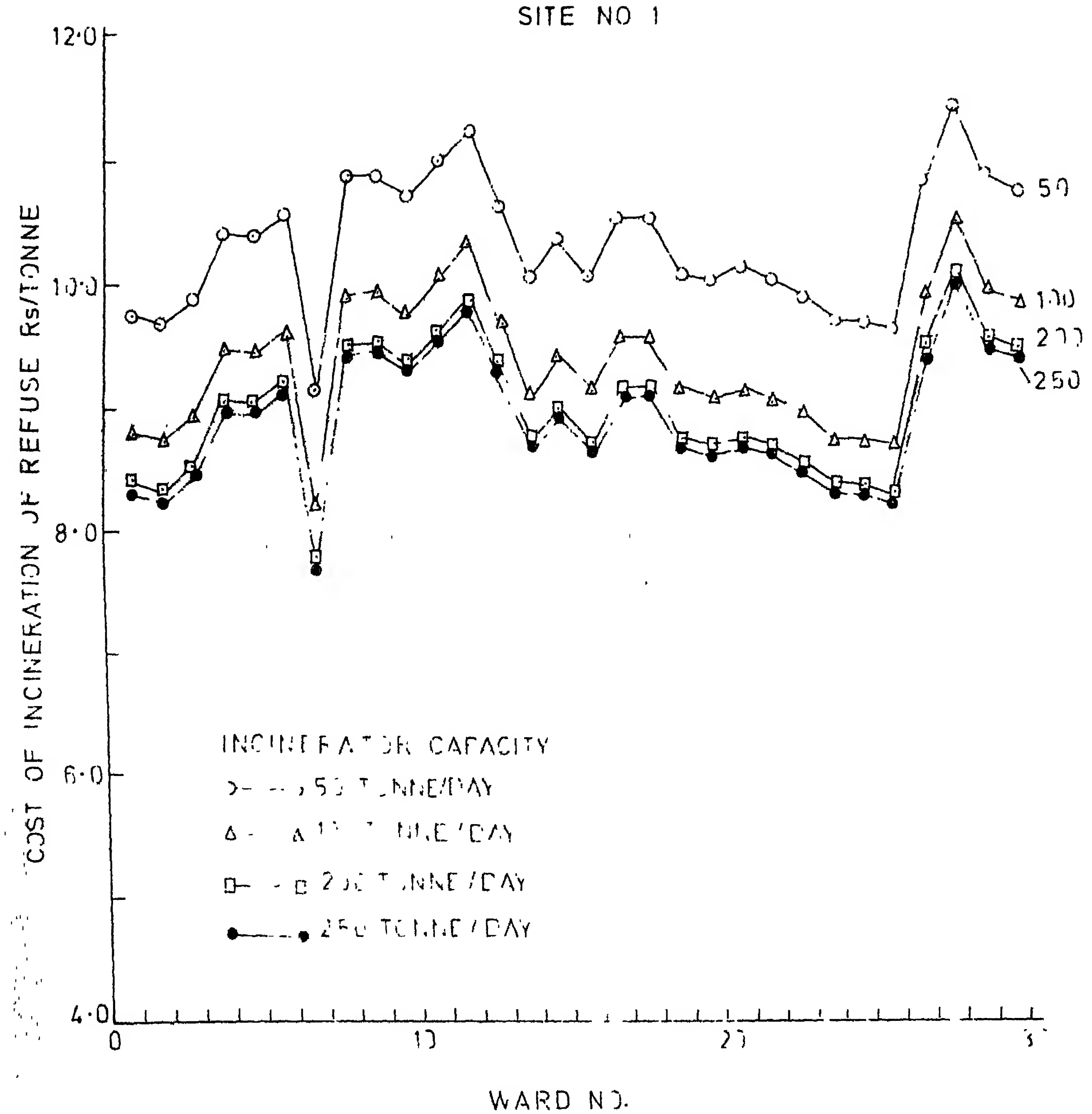


FIG. 6·4 VARIATION IN COST OF INCINERATION FOR DIFFERENT INCINERATOR CAPACITY AND WARD NOS.

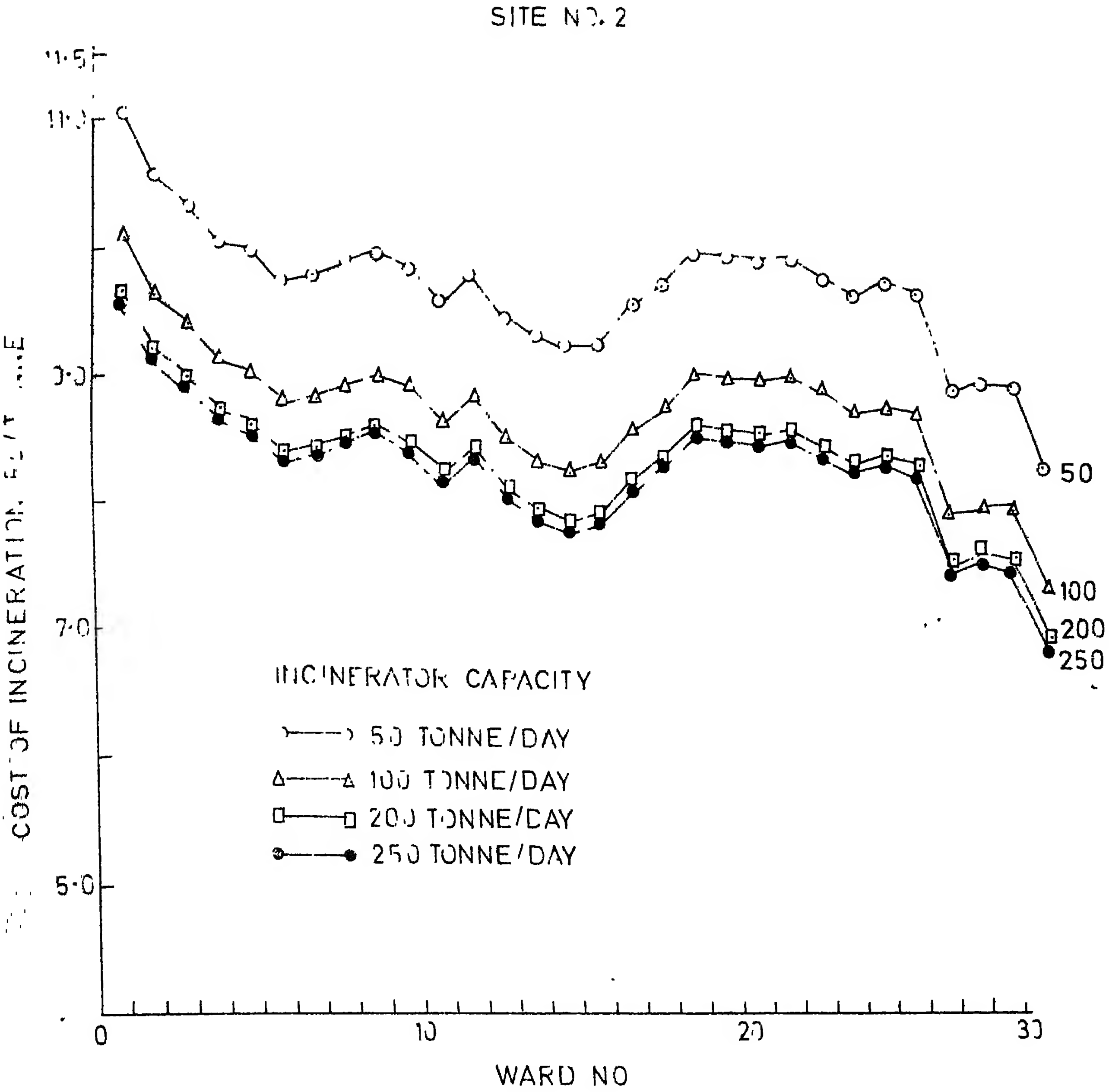


FIG. 6·5 VARIATION IN COST OF INCINERATION FOR DIFFERENT INCINERATOR CAPACITY AND WARD NOS.

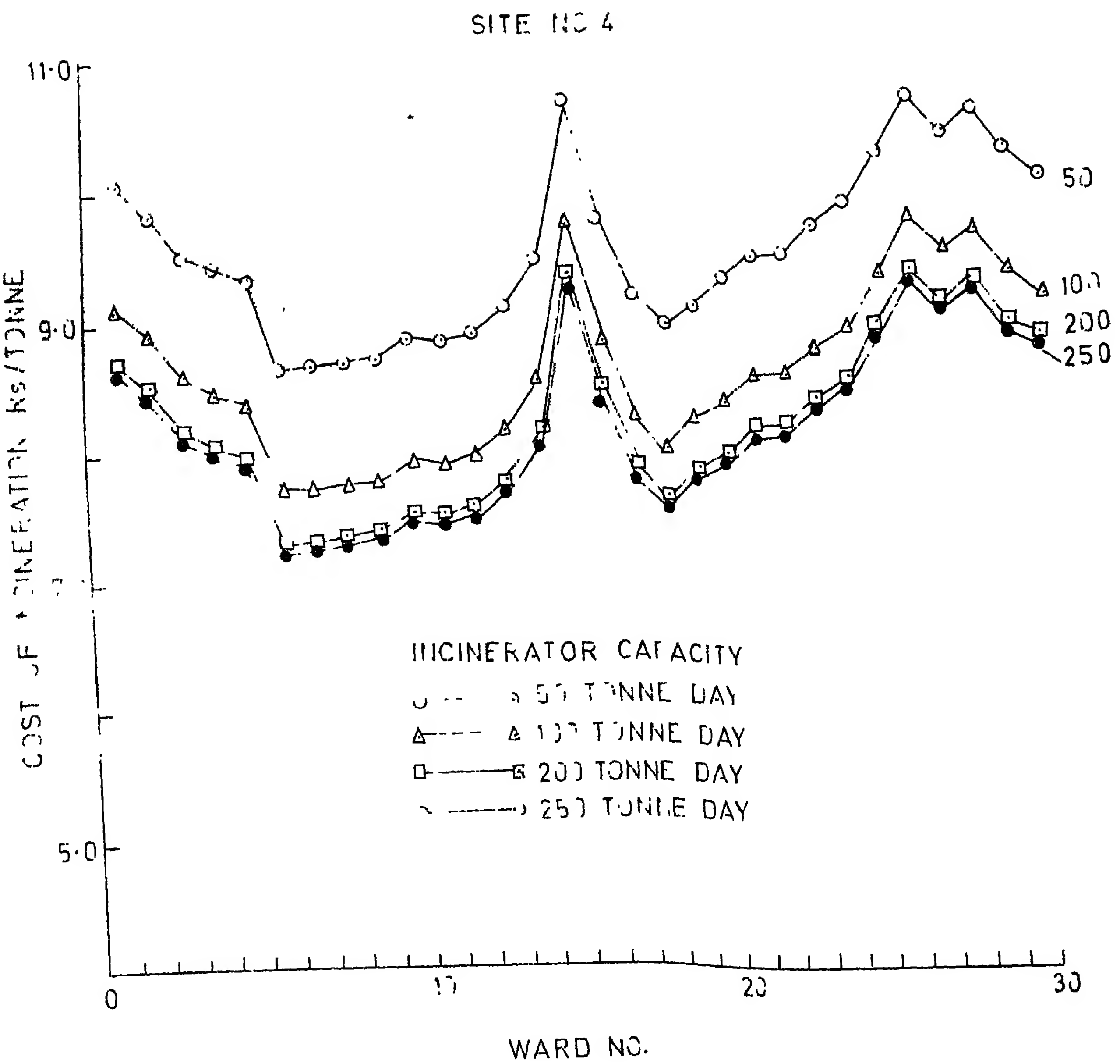


FIG. 6·7 VARIATION IN COST OF INCINERATION FOR DIFFERENT INCINERATOR CAPACITY AND WARD NOS

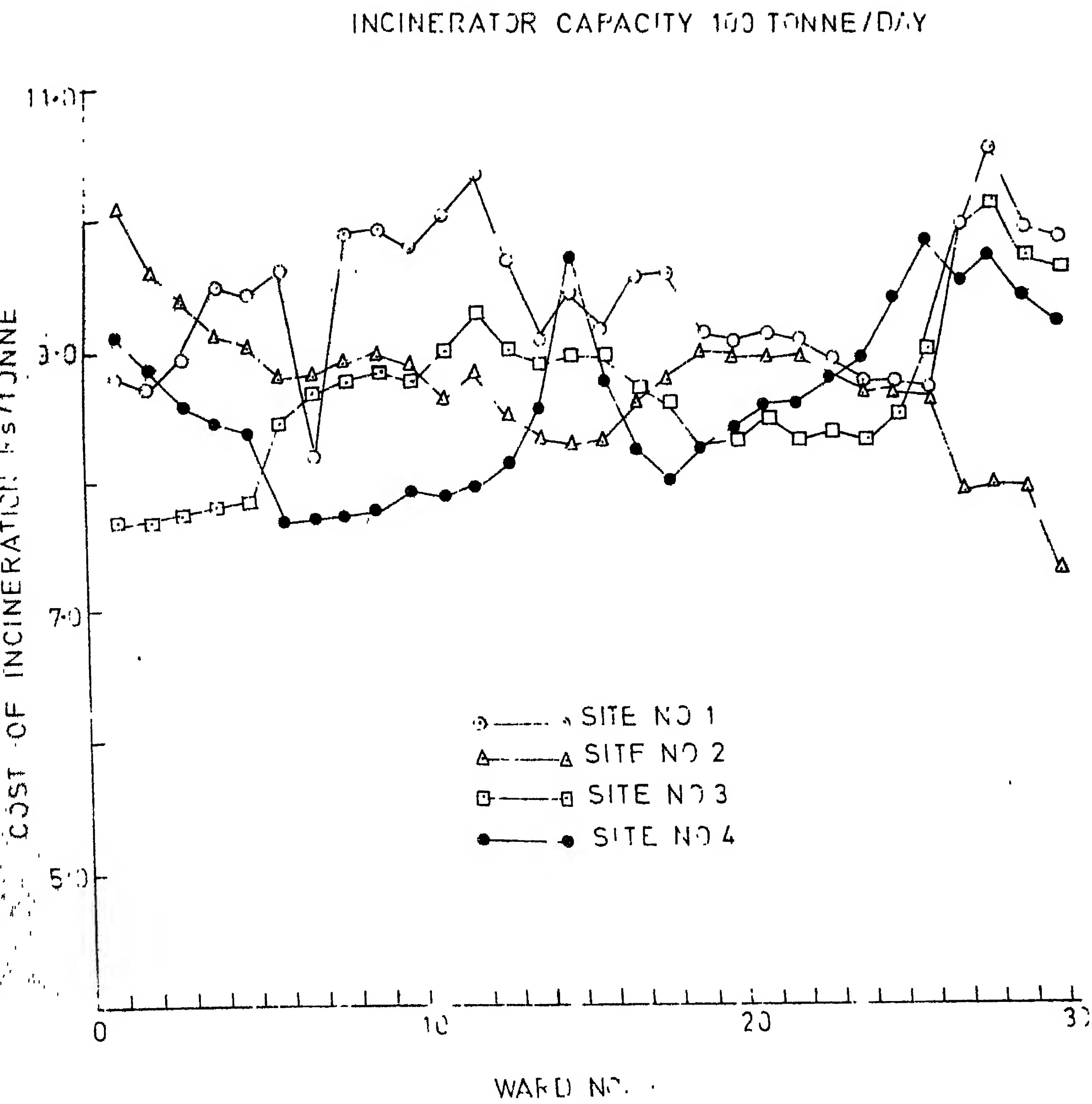


FIG. 6.8 VARIATION IN COST OF INCINERATION FOR DIFFERENT SITES AND WARD NOS.

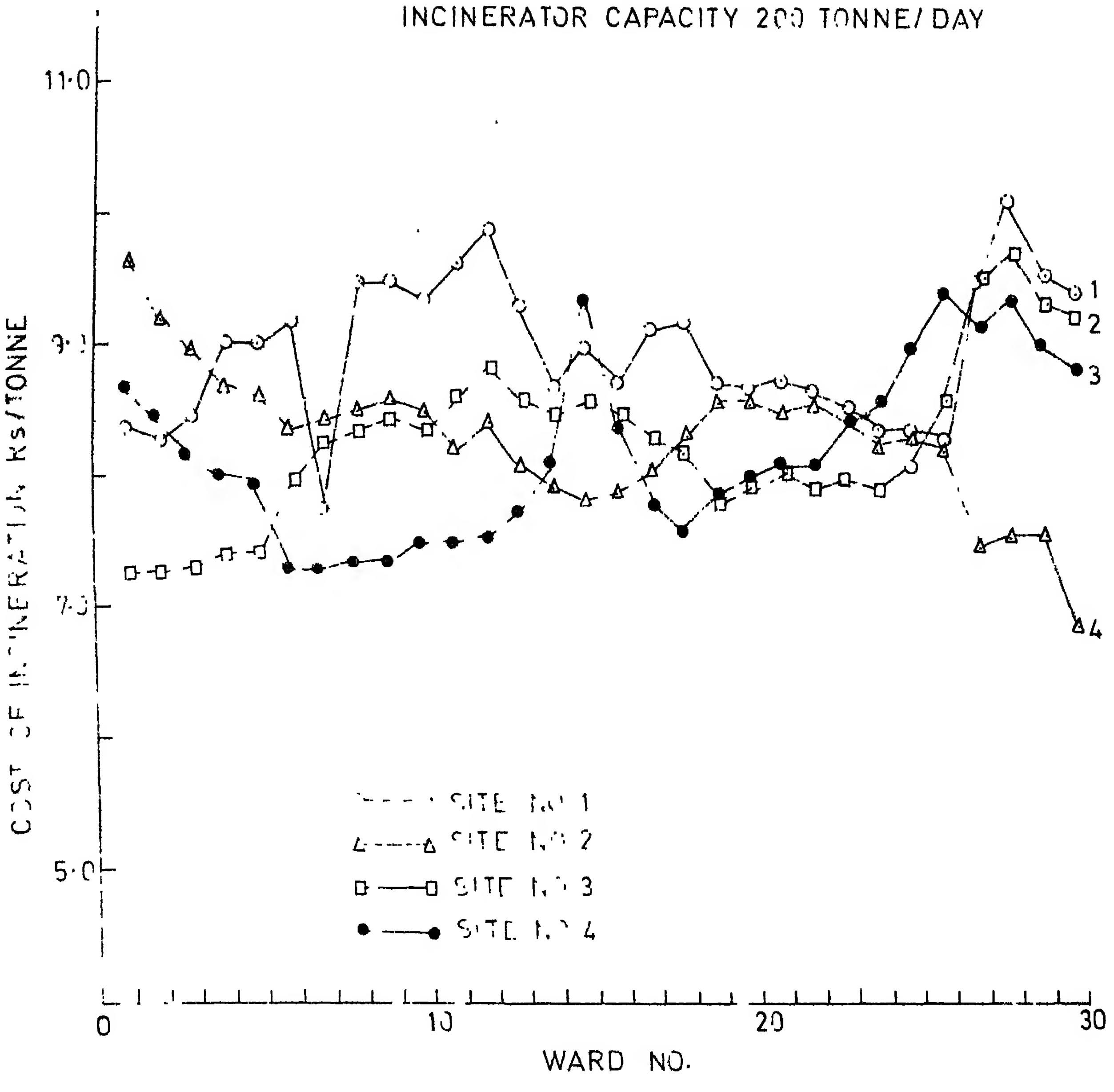


FIG. 6·9 VARIATION IN COST OF INCINERATION FOR DIFFERENT SITES AND WARD NOS.

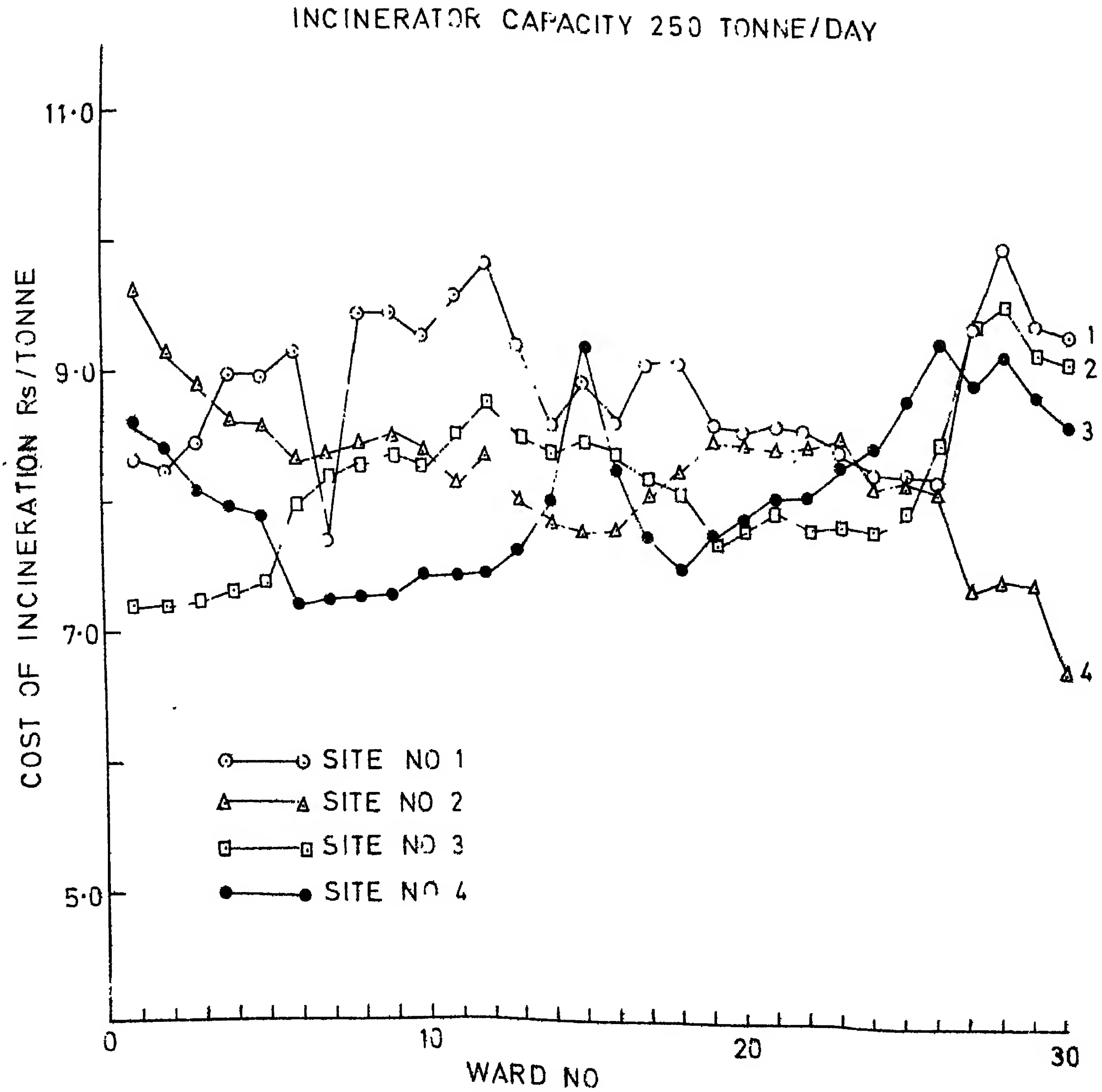


FIG. 6·10 VARIATION IN COST OF INCINERATION FOR DIFFERENT SITES AND WARD NOS.

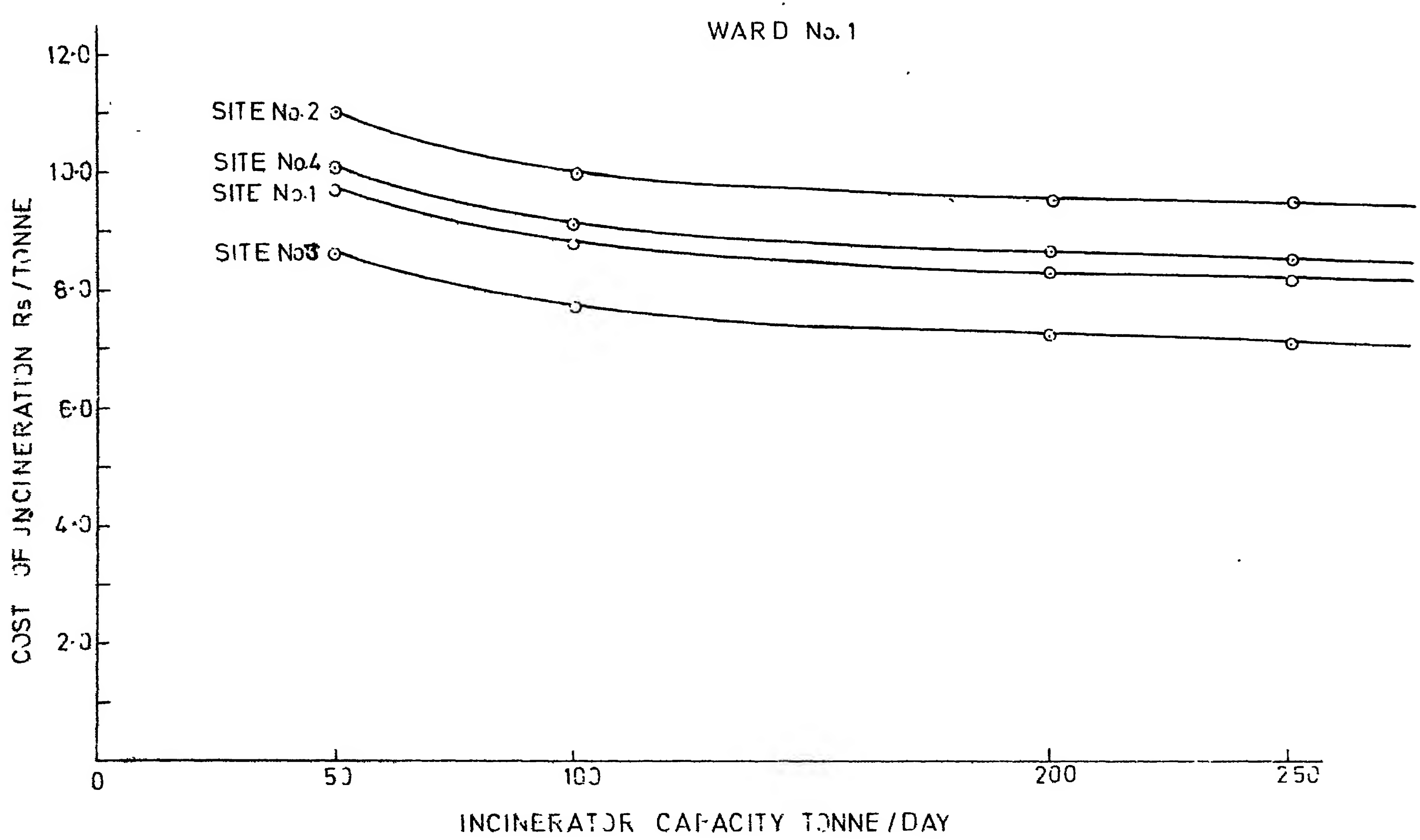


FIG. 5·11 RELATION BETWEEN COST OF INCINERATION AND INCINERATOR CAPACITY

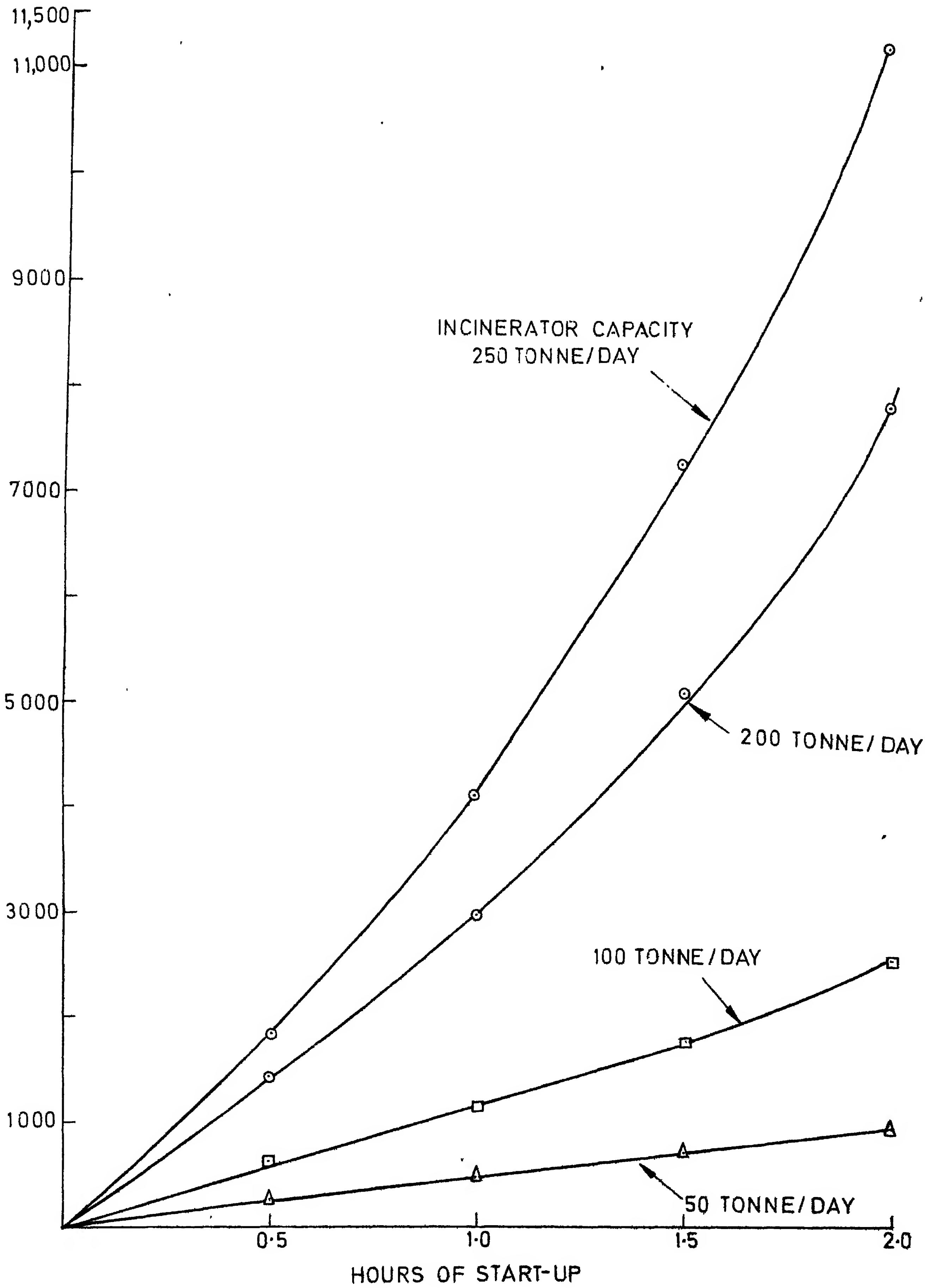


FIG. 6·12 RELATION BETWEEN COST OF AUXILARY FUEL & HOURS OF START-UP

TABLE 6.6: AUXILARY FUEL COSTS, RS/TONNE OF REFUSE, AT STEADY-STATE BURNING

(INCINERATOR CAPACITY = 100 TONNE/DAY)

Moisture Content of Refuse %	Calorific Values of Refuse		
	1,400 Kcal/Kg (40% Combustible Matter)	1,200 Kcal/Kg (30% Combustible Matter)	1,000 Kcal/Kg (20% Combustible Matter)
30	-12.1	-7.2	-2.2
40	-6.7	-1.8	3.2
50	-1.3	3.6	8.6
60	4.1	9.0	14.0

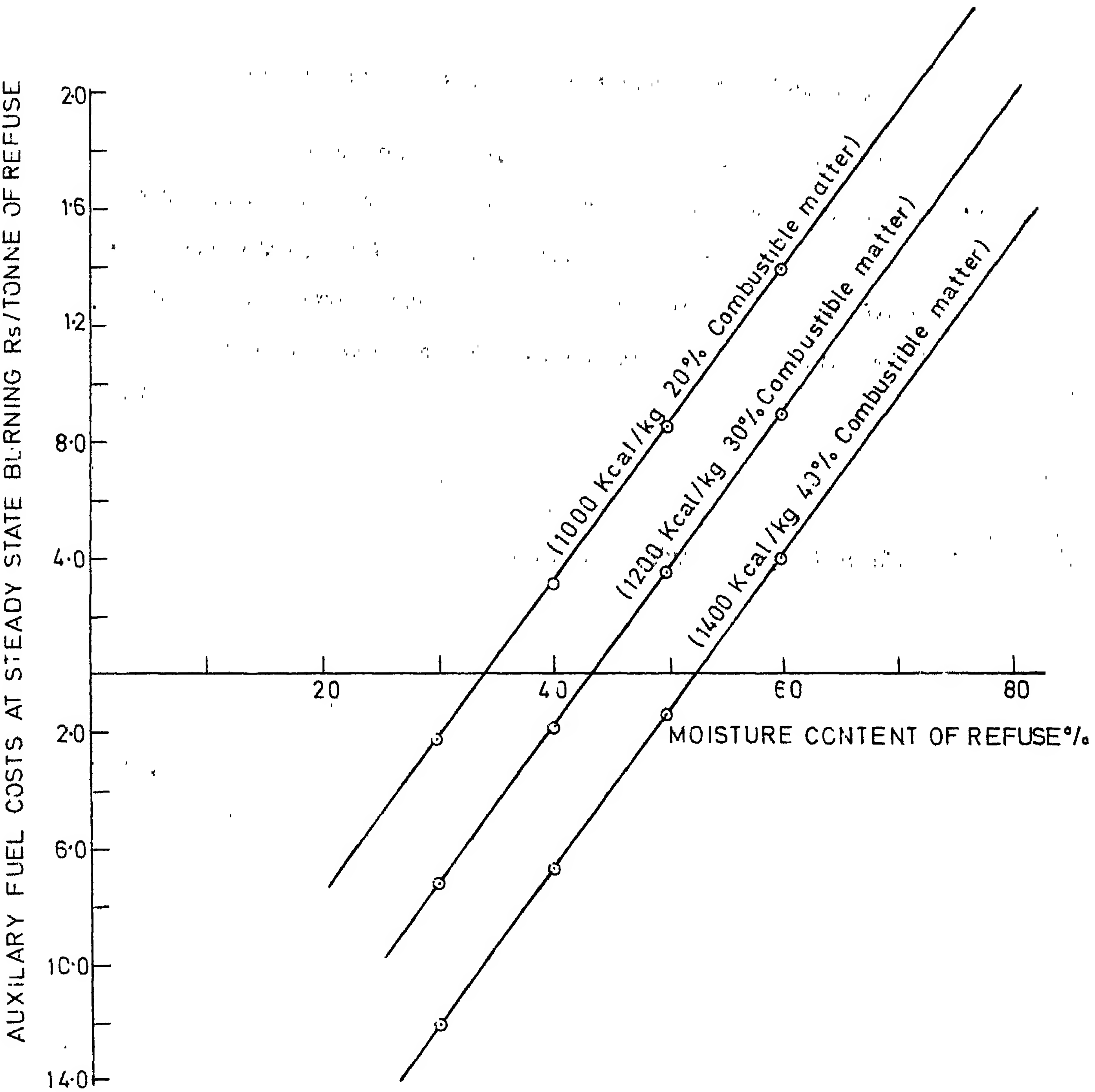


FIG. 6·13 AUXILARY FUEL COSTS AT STEADY STATE BURNING WITH DIFFERENT MOISTURE CONTENT OF REFUSE AT VARIOUS CALORIFIC VALUES OF REFUSE

6.4.2. Auxilary Fuel Costs at Unsteady-State Burning

The same parameters have been considered for determining the auxilary fuel costs at unsteady-state burning of incinerator, as have been considered in sec. 6.4.1. The costs figures are given in Table 6.7. The corresponding relationship between the chosen parameters is shown in Fig. 6.14.

6.5. INCINERATION COSTS

The incineration costs of refuse vary with the costs of transportation, capital investment, maintenance, depreciation, the incinerator capacity, and the characteristics of refuse.

6.5.1. Incineration Costs, Considering Various Characteristics of Refuse

In this incineration costs analysis same parameters have been considered as discussed in sec. 6.4.1. To show the corresponding relationship, refuse depot no. 5 was chosen arbitrarily to demonstrate the example for 100 and 200 T/day incinerator capacities. Table 6.8 shows the incinerator costs for 100 T/day incinerator capacity, for the refuse transported from depot no. 5, of various moisture content with different calorific values. Fig. 6.15 shows a relationship between incineration costs, moisture content of refuse

TABLE 6.7: AUXILARY FUEL COSTS, RS/TONNE OF REFUSE, AT UNSTEADY-STATE BURNING

(INCINERATOR CAPACITY = 100 TONNE/DAY)

Moisture Content %	Hours of Start-up	Calorific Values of Refuse		
		1,400 Kcal/Kg (40% Combustible Matter)	1,200 Kcal/Kg (30% Combustible Matter)	1,000 Kcal/Kg (20% Combustible Matter)
30	0.5	599.0	586.3	572.3
	1.0	1026.3	989.4	952.6
	1.5	1565.7	1496.5	1427.5
	2.0	2218.3	2107.5	1996.7
40	0.5	617.0	603.2	589.5
	1.0	1072.1	1035.3	998.5
	1.5	1651.8	1582.6	1513.5
	2.0	2356.1	2245.4	2134.6
50	0.5	634.1	620.4	606.6
	1.0	1118.0	1081.1	1044.3
	1.5	1738.0	1668.8	1599.6
	2.0	2494.0	2383.3	2272.5
60	0.5	651.3	637.5	623.7
	1.0	1163.8	1127.0	1090.15
	1.5	1824.0	1755.0	1685.7
	2.0	2632.0	2521.0	2410.4

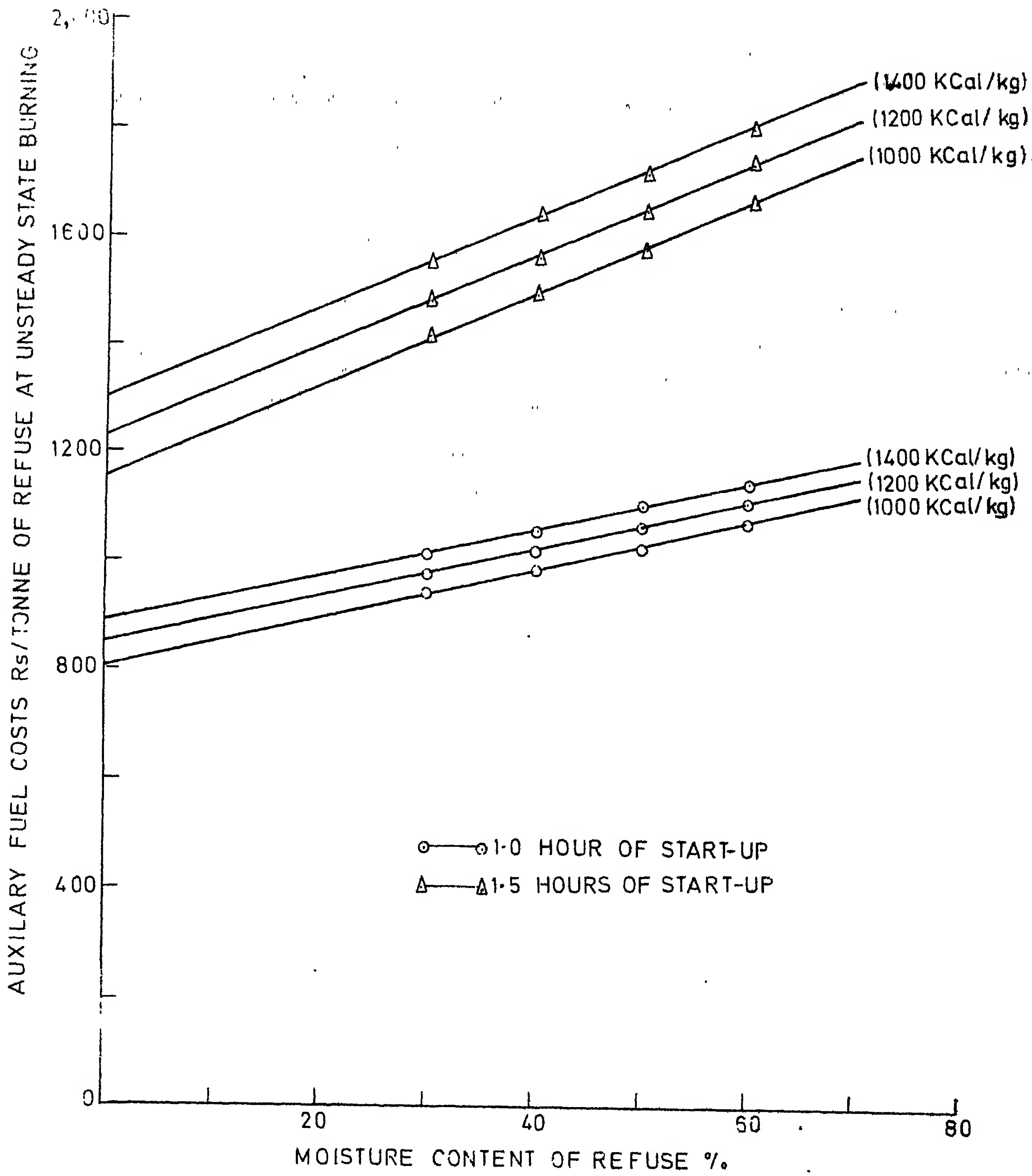


FIG. 6·14 AUXILARY FUEL COSTS AT UNSTEADY STATE BURNING WITH VARIOUS MOISTURE CONTENT AND DIFFERENT CALORIFIC VALUE OF REFUSE

TABLE 6.8: INCINERATION COSTS OF REFUSE

CONSIDERING:

INCINERATOR CAPACITY = 100 TONNE/DAY

REFUSE DEPOT NO. = 5

Moisture Content %	Calorific Values of Refuse		
	1,400 Kcal/Kg (40% Combustible Matter)	1,200 Kcal/Kg (30% Combustible Matter)	1,000 Kcal/Kg (20% Combustible Matter)
30	-5.2	-0.37	4.5
40	0.16	5.0	9.9
50	5.6	10.5	15.3
60	11.0	15.8	20.7

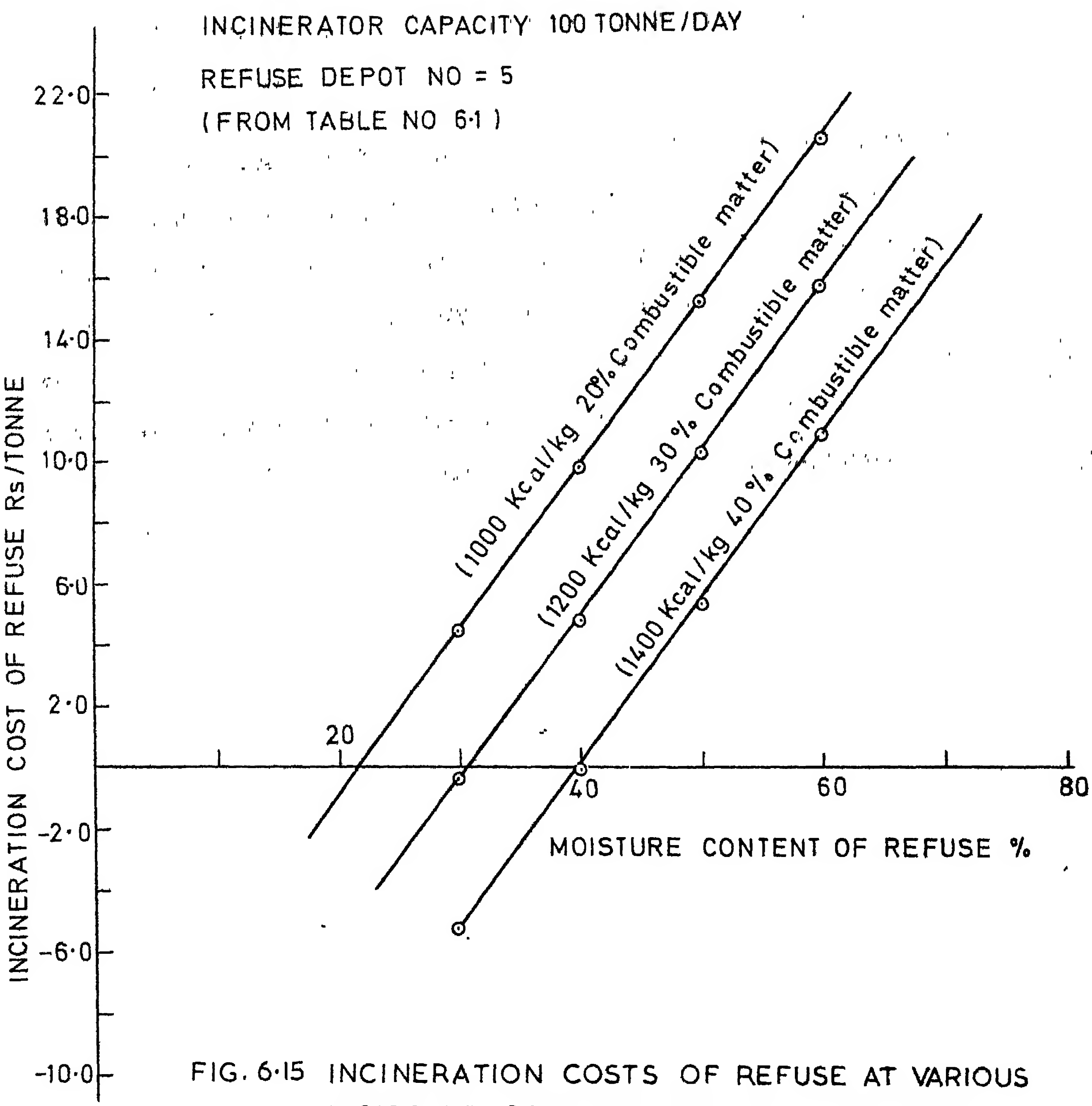


FIG. 6·15 INCINERATION COSTS OF REFUSE AT VARIOUS MOISTURE CONTENTS AND AT DIFFERENT CALORIFIC VALUES OF REFUSE

with different calorific values of refuse.

6.5.2. Incineration Costs of Different Incinerator Capacities

As previously considered the different incinerator capacities as 50, 100, 200 and 250 T/day. Various data for determining the incineration costs are shown in Appendices II to V. These data already have been used for calculating the incineration costs as given in Tables 6.2, 6.3, 6.4 and 6.5. In the Fig. 6.16 irrespective of the transportation costs, the incineration costs for different incinerator capacities are shown.

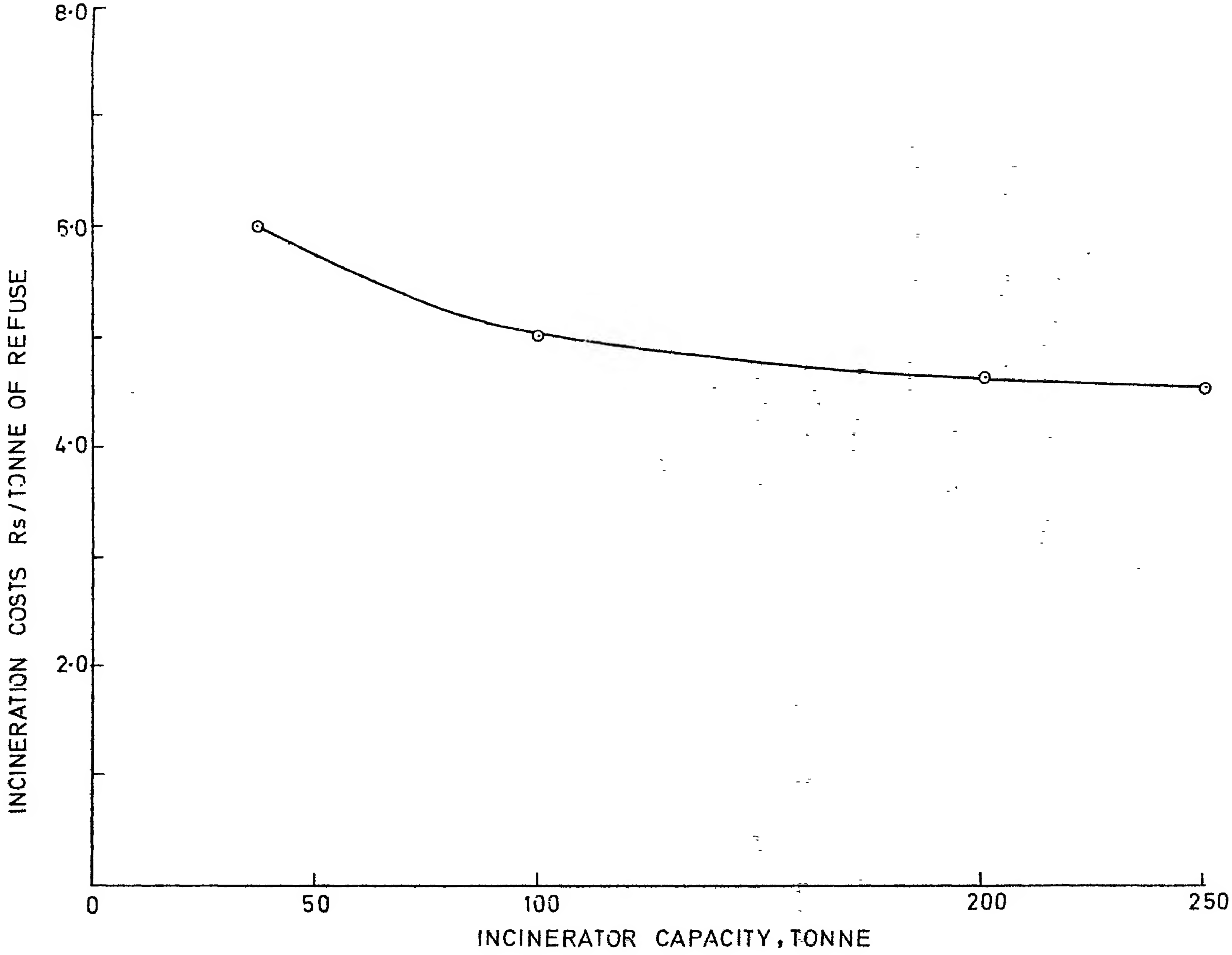


FIG. 6·16 VARIATION IN INCINERATION COSTS OF REFUSE WITH INCINERATOR CAPACITY

CHAPTER VII

DISCUSSION

In the present study two alternative methods of refuse disposal were considered

1. Dumping of refuse for landfill

and 2. Incineration of refuse.

Since the Kanpur city is expanding very rapidly and the areas of expansion are only in the direction of westwards and southwards, because on the East side of the city Cantonment Board is situated and on the North side of the city river Ganges is flowing. The present outskirt areas of the city are mostly deeply excavated land the earth having been reproved for brick kilns, particularly in the West side of the city. Since the city is growing very fast, people have started building their houses on these excavated areas. To fill up this land Refuse Disposal Department of Kanpur Nagar Mahapalika started dumping the city refuse on these low lying areas. But it has been observed that the dumping of refuse is not being done properly from the health point of view. No proper care is being taken to avoid the health hazards created by just dumping the refuse on dumping sites. Hence the other method of refuse disposal that is refuse disposal by incineration was taken into consideration. Since filling up of the land is a major problem on the

outskirts areas of the city so thought on composting of refuse was not given in this study. There are the following reasons for which composting of refuse was not considered.

(i) Manual or mechanical composting plants require a large area which is not possible to get around the city.

(ii) Moreover, though mechanical composting plant requires lesser area than manual composting plant but the initial cost involved in mechanical composting plants is generally tremendously high.

(iii) Since all the low lying areas are first to be filled up, so it was thought of building incinerator on these low lying sites so that the residue or ashes can be filled up on these areas without creating any health hazards and with a negligible transportation cost of residues, and since, the reclamation of the land with this residue is much faster than by just dumping the raw refuse without adopting any proper controlled practices.

In this study a cost analysis is carried out by considering the above two methods of refuse disposal. As it has been observed that no systematic method of refuse dumping is being adopted, which results in an uneconomical way of refuse dumping. From this study it has been found that:

1. As shown in Fig. 6.2, the variation in refuse transportation costs for various ward, for the two refuse dumping sites, it can be determined as to which refuse dumping site will be economical for which ward. As it has been found that the refuse of ward nos. 1, 2, 3, and 7 should go to dumping site no. 1. Whereas from the rest of the wards the refuse should be dumped on site no. 2.
2. Though there is much fluctuation in the refuse transportation cost but it depends on the quantity of refuse produced in the ward. The quantity of refuse produced from a community depends on the contributing population strength and the quantity produced per person (which depends on the standard of living etc.) represented by per capita refuse production.
3. The same results have been obtained from the Fig. 6.3 where the transportation cost per tonne has been considered against ward nos. It also shows that refuse from ward nos. 1, 2, 3 and 7 should go to dumping site no. 1. Whereas from the rest of the wards the refuse should go to dumping site no. 2.

In the cost analysis of refuse disposal by incineration the following points were observed:

1. From the Fig. 6.4 it is clear that there is a great difference in the cost of incineration for the incinerator

capacities of 50, 100 and 200 tonnes/day. There is very little difference in the cost of incineration between 200 and 250 tonnes/day capacity of incinerators.

2. From the Figures 6.5, 6.6 and 6.7 drawn for site nos. 2, 3 and 4, it is evident that the variation in cost of incineration of refuse for different incinerator capacity is same. It has also been seen that between the 200 tonne/day and 250 tonne/day capacity incinerator there is only a cost difference of Rs. 0.07 approximately.

3. Having only Rs. 0.07 difference in cost of incineration of refuse between 200 tonne/day and 250 tonne/day capacity incinerator, it would be beneficial if 200 tonne/day capacity incinerators are installed. Because the initial cost and maintenance cost are comparatively lesser than 250 tonne/day capacity incinerator.

4. From the Figures 6.4, 6.5, 6.6 and 6.7 it has been found that it would be better to install a 200 tonne/day capacity incinerator but however, to compare the cost of incineration of refuse for each 100, 200 and 250 tonne/day capacity incinerator on different 4 sites, Figures 6.8, 6.9 and 6.10 drawn respectively. Taking into consideration the incinerator capacity of 200 tonne/day. Fig. 6.9 shows the variation in cost of incineration for different sites and wards. From this figure it can be easily determined that if on all the four sites a

200 tonne/day capacity incinerators are installed, which incinerator or site will be served by which wards. From the Fig. 6.9 a tabulated form is given to show that which of the wards will be served by which incinerator site.

Incinerator site no.	Ward served
1	....
2	14, 15, 16, 26, 27, 28, 29, 30
3	1, 2, 3, 4, 5, 19, 20, 21, 22, 23, 24, 25
4	6, 7, 8, 9, 10, 11, 12, 13, 17, 18

This type of distribution gives comparatively minimum cost of transportation and incineration of refuse.

5. From Fig. 6.11, it has also been observed that there is very little difference in the cost of incineration as the capacity of incinerator increases beyond 200 T/day.
6. It has been found in computing the values of cost of incinerator of refuse that if the heat value of refuse is 2000 Kcal/Kg and 100 percent excess air (theoretical) is supplied, there is no auxilary fuel required. Similarly no auxiliary fuel was required when the heat value of refuse was 1400 Kcal/Kg and 100 percent excess air was used or when the heat value of refuse was 2000 Kcal/Kg with 200 percent excess air used. The auxilary

fuel is only required when the heat value of refuse is 1400 Kcal/Kg and 200 pércent excess air is used as it has been mentioned by Meissner [31] in a heat balance all of the heat input must be acoounted for. When there is no excess of heat input over losses the furnace temperature will remain uniform, which occurs with 200 percent excess air. When the excess air is reduced to 150 percent there is an excess of input over losses and the temperature rises. For the above statement heat value of refuse was considered as 3315 Kcal/Kg. The reason of considering the heat value of refuse in the present study as 1400 Kcal/Kg is that from the Table 4.1 the average heat value of Kanpur refuse was found to be 1350 Kcal/Kg and therefore 1400 Kcal/Kg was considered.

7. It has also been observed from the Fig. 6.12 that in unsteady-state burning the cost of auxilary fuel is quite high. In the unsteady-state it was assumed that the heat input is only given by auxilary fuel where as in actual practice refuse also contributes some heat input, which ultimately reduces the cost of auxilary fuel required during the start-up of the incinerator. It is also seen from this figure that quicker the time of start-up the lessen is the cost of auxilary fuel.

8. As it is seen from the Figure 6.13 that the refuse having 1400 Kcal/Kg calorific value, the auxilary fuel cost is lesser at steady-state burning of this refuse than the other two types of refuse having 1200 and 1000 Kcal/Kg calorific values. It has been observed that a negative auxilary fuel cost has been found cut almost for all types of refuse. The degree of negativity with various moisture content of refuse is increasing as the calorific value of refuse becomes higher. It is obvious from this study that in the incinerator the heat liberated by refuse is much more than the heat losses, and hence the negative auxilary fuel cost has occurred. It can be also observed from this figure that at which moisture content of refuse the auxilary fuel costs will be zero for different types of refuse having different calorific values.

9. As it is shown in Fig. 6.14, the costs of auxilary fuel at unsteady-state burning increases with the calorific value of refuse and the time of start-up of incinerator. Actually in practice, with the increase in calorific value of refuse, the auxilary fuel cost should not increase. But here, theoretically, the losses are loss with lesser calorific value of refuse and hence the less costs of auxilary fuel have been observed in lesser calorific values.

Time is a main factor in start-up of the incinerator. As the start-up time increases, the losses in incinerator increases which results in increase in auxilary fuel costs as shown in Fig. 6.14 for 1.0 hour and 1.5 hours of start-up of incinerator.

10. As evident from the Fig. 6.15, the incineration cost of refuse increases with decrease in calorific value of refuse. Here also the reason for getting the negative incineration costs is the same as discussed in the cost of auxilary fuel at steady state in point 11. In this figure it does not mean that the other costs such as transportation costs, labor costs, electrical charges, initial investment, maintenance and depreciation have not taken into account. By having considered these costs the incineration costs come out to be negative. The reasons being are the same as discussed above.

11. It has been observed from the Fig. 6.16, that the incineration costs of refuse decrease with the increase in incinerator capacities. The main factor which affects this cost is the cost of initial investment, maintenance cost and depreciation. It has been observed that as the incinerator capacity increases these costs decrease substantially. There has been a very less change was observed in the auxilary fuel cost during

incineration.

12. It has also been observed from this study that there is a very little difference in the incineration costs of 100 T/day and 200 T/day incinerator capacities. The incineration costs of 200 T/day was come out to be Rs. 0.4/tonne more than the 100 T/day incinerator, for all calorific values of refuse and moisture contents.

CHAPTER VIII

CONCLUSIONS

From this study the following conclusions can be drawn.

1. Though it has been observed that refuse dumping is cheaper than refuse incineration but due to rapid expansion of the city and due to uncontrolled dumping of refuse this method does not seem to be desirable to continue in future.
2. The public is now also becoming aware of the facts and effects of dumping the raw refuse near any residential locality. Due to aesthetic view point and other nuisance causing reasons public do not allow the authorities to dump the refuse in nearby areas. Hence it can be concluded that unless proper sanitary landfilling practices are adopted, the refuse dumping will have to be discontinued.
3. As far as the incineration of refuse is concerned though it is costlier but it seems to be feasible in near future. The main advantage of this type of refuse disposal method is that the residues left after burning of refuse can be used for landfilling without any objectionable after effects.

4. It has also been concluded from the computed results that for a refuse having heat value of 1400 Kcal/Kg and 100 percent excess air supply, no auxiliary fuel will be required which makes the process of incineration cheaper.
5. This study also reveals that the cost of incineration can be lowered down if the capacity of incinerator is increased.
6. It has been observed from this study that higher the calorific value of refuse the lesser will be the auxiliary fuel cost. It can be found out that at which calorific value and moisture content of refuse the auxiliary fuel cost will be negligible. As shown in Fig. 6.13, for the calorific value as 1400 Kcal/Kg at 55% moisture, for 1200 Kcal/Kg at 46% moisture and for 1000 Kcal/Kg at 38% moisture content of refuse the auxiliary fuel costs will be zero or in other words for such characteristics of refuse no auxiliary fuel will be required during incineration.
7. The negative costs of auxiliary fuel during steady-state condition indicate that more of heat is being liberated by refuse which can be utilized for steam generation, and other heating purposes.
8. When the costs of incineration become negative considering other operating costs with auxiliary fuel

cost, it can be concluded that the refuse is liberating so much of heat in terms of auxiliary fuel cost that it has overcome the other operating costs. For making the incineration process cheaper the best way is to utilize its heat generated during incineration which ultimately reduces the cost of operation, maintenance etc.

9. On an average the refuse generated from the wards served by incinerators 2, 3 and 4 is about 250 T/day. Hence incinerator of capacity 250 T/day may be installed in these regions.

10. In rainy seasons the moisture content of the refuse will be considerably high and therefore incineration of refuse may prove to be uneconomical from the point of view of the extra auxiliary fuel requirements.

CHAPTER IX

SUGGESTIONS FOR FUTURE WORK

1. To get a better estimate of refuse transportation cost and the cost of refuse incineration, it would be preferable to consider the haul distances by taking into consideration each refuse storage depot rather than the average distances of all refuse storage depots of each ward from disposal site.
2. For getting a more effective disposal method, refuse of different characteristics from different wards suitable for the particular disposal system should be taken into consideration. This criteria of refuse characteristics should also be independent variable in the developed mathematical model.
3. The cost of refuse transportation considered in case of refuse dumping is much larger than the actual landfilling process. By considering each and every aspect of landfilling the cost for this type should be revised upwards.
4. Though it has been observed from this study that the cost of incineration is greater than the cost of refuse transportation and landfilling, the cost of incineration can be reduced by utilizing the heat

generated during incineration for power supply, steam generation, heating purposes etc. which may yield significant financial returns. A more comprehensive mathematical model should be developed by considering all the above factors to get a more precise disposal cost.

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APPENDIX I

COST OF REFUSE DUMPING

Presently the city refuse is being dumped on the two sites as discussed earlier. The following cost has been calculated for the year 1970-1971.

1.	Pay of Drivers	
	No. of drivers 69	
	@ Rs. 155 per month	= Rs. 1,28,400
2.	Pay of Loading & Unloading Personal	
	No. 400	
	@ Rs. 135 per month	= Rs. 6,48,000
3.	Pay of Jamadars	
	No. 80	
	@ Rs. 130 per month	= Rs. 1,24,800
4.	Pay of Over-head Staff	
	For one year	= Rs. 3,45,000
5.	Maintenance of Trucks	
	No. 50	
	@ Rs. 3000 per year	= Rs. 1,50,000
6	Cost of Petrol Consumed	
	in the year 1970-1971	= Rs. 7,23,800

7. Land Cost:

The land already belongs to Corporation and its cost @ Rs. 6,000/- per acre

Total land 400 acre

This money, if invested in Government securities, would yield a 6 percent interest, hence this amount can be considered as yearly expences on land.

Therefore cost on land $= 400 \times 6000 \times \frac{6}{100}$

= Rs. 1,44,000

Therefore the total cost comes out to be by adding from (1) to (7) = Rs. 23,64,000

The population served in the year 1970-1971 = 9,44,000

Hence the expence/capita-year = 23,64,000/9,44,000

= Rs. 2.48

Rs. 2.50 (say).

APPENDIX II Continued

9.	Theoretical air required	Assuming 100% excess air 570 Kg of air/ $252x10^3$ Kcal[15]	10,000 Kg/hr	19,000 Kg/hr	38,000 Kg/hr	47,000 Kg/hr
10.	Stack gas weight; The gas weight leaving the stack	100% excess air required + combustible in refuse + moisture in refuse[56]	11,400 Kg/hr	21,940 Kg/hr	43,880 Kg/hr	54,280 Kg/hr
11.	Gas volume at 800°C	1 Kg of air = 0.9 M^3[56]	170 M^3/min	330 M^3/min	660 M^3/min	815 M^3/min
12.	Stack area	Assuming the gas velocity in stack at 800°C = 330 M/min[56]	0.52 M^2	1 M^2	2 M^2	2.47 M^2
13.	Diameter of stack	...	0.81 M	1.13 M	1.6 M	1.77 M
14.	Height of the stack	Stack extends not less than 1 M above any roof within 15 M of the top of the stack[64]	15 M above the grate	15 M above the grate	15 M above the grate	15 M above the grate
15.	Number of blower required for induced draft	Rated capacity of blower: 4.425 Tonne of air/hr	4	6	10	12

APPENDIX III

COST ANALYSIS OF INCINERATORS

No.	Parameters		Incinerator Capacity, Tonne/day		
		50	100	200	250
1.	Civil works:				
	(a) Incinerator	Rs. 72,500	1,00,000	1,46,200	1,60,000
	(b) Other Buildings	Rs. 20,000	20,000	25,000	25,000
	(c) Land	Rs. 40,000	40,000	40,000	40,000
2.	Mechanical and Electrical equipments:				
	(a) Grate	Rs. 10,000	20,000	40,000	60,000
	(b) Blowers	Rs. 16,000	25,000	40,000	55,000
	(c) Burners and other fittings	Rs. 4,000	5,000	5,000	5,000
	(d) Weighing bridge	Rs. 30,000	30,000	30,000	30,000
	Total Rs.	1,95,000	2,40,000	3,30,200	3,75,000

APPENDIX IV

DATA REQUIRED FOR THE COMPUTATION OF REFUSE TRANSPORTATION COST*

Abbrivia-tions used in computer programming	Parameters	Values
C	Cost of fuel (Petrol)	Rs. 1.48 per litre
FC	Average mileage of a vehicle	2.88 km per litre
CM	Cost of mobile oil	Rs. 3.50 per litre
MC	Mobile oil consumption	168 km per litre
VM	Average maintenance cost of a vehicle per year	Rs. 3000 per year
RN	Average run by a vehicle in km per year	20,000 km per year
I1	Initial cost of a vehicle (Purchased in auction)	Rs. 17,000
I2	Salvage value of a vehicle	Rs. 2,500
LV	Average life of a vehicle in km	2,90,000 km
PD	Pay of a driver	Rs. 155 per month
WHM	Working hours in a month	240 hours
PL	Pay of a labor	Rs. 135 per month
NL	Number of labor per truck	6
RL	Quantity of refuse loaded by a labor	0.8 Tonne per hour

Appendix Continued...

APPENDIX IV Continued

RU	Quantity of refuse unloaded by a labor	1.6 Tonne per hour
RV	Average capacity of a vehicle	4.8 M^3
SP	Average speed of a vehicle	30 km per hour
RHO	Density of refuse	584 Kg per M^3

* Data collected from Refuse Disposal Department, Kanpur Nagar Mahapalika, Kanpur.

APPENDIX V

DATA REQUIRED FOR THE COMPUTATION OF COST OF INCINERATION OF REFUSE

Abbreviation used in Computer Programming	Parameter	Incinerator Capacity, Tonne/day			
		50	100	200	250
Q1	Initial cost of civil work[1], in Rs.	1,35,000	1,60,000	2,15,000	2,25,000
Q2	Salvage value[1], in Rs.	2,700	3,200	4,300	4,500
NI	Useful life of incinerator[1] (civil work), in years	10	10	10	10
MI	Useful life of electrical and mechanical equipment[1], in years	10	10	10	10
M1	Initial cost of electrical and mechanical equipment[2], in Rs.	60,000	80,000	1,15,000	1,50,000
M2	Salvage value of electrical and mechanical equipment[2], in Rs.	3,000	4,000	5,750	7,500
HP	Rated Horse power of a blower	10	10	10	10

Appendix Continued...

APPENDIX V Continued

HR	Total heat liberated by refuse per hour[3], Kcal/hour	~~28x~~ 28x10^5	58.8x10^5	117.6x 10^5	145.6x10^5
QR	Incinerator loading[1] tonne/hour	2.0	4.2	8.4	10.4
HW	Working hours of an incinerator per year[1]	7,200	7,200	7,200	7,200
CMI	Maintenance cost of an incinerator, Rs/year	2,700	3,200	4,300	4,500
CMM	Maintenance cost of electrical and mechanical equipments[2], Rs/year	3,000	4,000	5,750	7,500
QI	Quantity of refuse handled by a labor on incinerator[1], tonne/hour	1.0	1.0	1.0	1.0
PLI	Pay of a labor working on incinerator Rs/month	150	150	150	150
WHM	Working hours of a labor per month	240	240	240	240
AQ	Quantity of air required (theoretical, 200% excess air) per 252x10^3 Kcal[3], in tonne	0.852	0.852	0.852	0.852

Appendix Continued...

APPENDIX V Continued

QAB	Quantity of air produced by a blower, tonne/hour	4.425	4.425	4.425	4.425
CF	Cost of electric power Rs/KWH	0.10	0.10	0.10	0.10
TF	Furnace temperature at steady state, °C	800°C	800°C	800°C	800°C
TO	Surrounding atmospheric temperature	30°C	30°C	30°C	30°C
CAF	Cost of auxilary fuel[62] Rs/tonne of fuel	500	500	500	500
FINERT	Percentage of inert (ash) material present in refuse	0.3	0.3	0.3	0.3
COMBUS	Percentage of combustible material present in refuse	0.4	0.4	0.4	0.4
CPI	Specific heat of inert material[4], Kcal/tonne°C	190	190	190	190
HRPT	Heat liberated per tonne of refuse[3], Kcal	$14x10^5$	$14x10^5$	$14x10^5$	$14x10^5$
HF	Heat liberated by per tonne of auxilary fuel[62], Kcal	$10.75x10^6$	$10.75x10^6$	$10.75x10^6$	$10.75x10^6$

Appendix continued...

APPENDIX V Continued

CPA	Specific heat of air[4], Kcal/tonne-°C	240	240	240	240
CV	Specific heat of water vapour[4], Kcal/tonne-°C	1,000	11,000	1,000	1,000
CW	Specific heat of moisture[4] (water), Kcal/tonne-°C	1,000	1,000	1,000	1,000
LAMDA	Latent heat of water vapour[4], Kcal/tonne	$54x10^4$	$54x10^4$	$54x10^4$	$54x10^4$
K	Thermal conductivity of wall material[4], Kcal/M-hr-°C	0.02478	0.02478	0.02478	0.02478
ETA	Humidity in air[4], tonne of humidity/tonne of air	0.01736	0.01736	0.01736	0.01736
W	Thickness of the furnace wall[1], in M.	0.35	0.35	0.35	0.35
A	Area of furnace wall[1], in M^2	48	68	104	118
MOS	Moisture present in refuse percentage	0.3	0.3	0.3	0.3
QM	Quantity of moisture present in refuse, tonne of moisture/tonne of refuse	0.3	0.3	0.3	0.3

Appendix continued...

APPENDIX V Continued

ND	Natural draft	0	0	0	0
TC	Capacity of a truck, in tonne	2.8	2.8	2.8	2.8
IR	Rate of interest percent per annum	7	7	7	7
WINC	Weight of furnace walls[3], tonne	55	80	120	135
CPINC	Specific heat of wall material[4], Kcal/tonne-°C	200	200	200	200

1 Designed data
2 Estimated data
3 Calculated data
4 From: "Chemical Engineer's Hand Book", By Perry, J.H., 4th Edition, N.Y., McGraw Hill, 1963.

APPENDIX VI

OTHER NOTATIONS USED IN COMPUTER PROGRAMMING

Notations	Parameters
N	Number of average distances from each ward upto dumping ground or incinerator
CF	Cost of fuel (Petrol)
CMO	Cost of mobile oil
CMV	Maintenance cost of a vehicle
CDV	Depreciation cost of a vehicle
MU	Useful life of vehicle in years
CIV	Interest cost of a vehicle
CO	Total vehicle cost
CD	Pay of a driver per hour
CL	Pay of a labor per hour
TL	Time for loading the refuse
TU	Time for unloading the refuse
DI	Average distance from a ward i to the dumping ground
C(I)	The cost of clearing the refuse from ward i
GT	Total volume of refuse in a ward i
G(I)	Quantity of refuse produced in ward i per week
X(I)	Number of trips from a ward i per week
COST(I)	Refuse transportation cost from a ward i to the dumping ground. Rs/week

Appendix continued...

APPENDIX VI Continued.

QAIR	Quantity of air required in tonne to burn one tonne of refuse
QF	Quantity of auxilary fuel required in tonne to burn one tonne of refuse
AA	Heat lost through air
AB	Heat lost through humidity present in air
AC	Heat lost through inert material present in refuse
AD	Heat lost through the moisture present in refuse
HTC	Heat transfer coefficient of furnace wall material
AE	Heat lost through the furnace walls
AF	Total heat liberated by refuse per hour
AG	Heat lost through combustible material present in refuse
QF1	Quantity of auxilary fuel required without considering the air required for auxilary fuel
QAFUEL	Quantity of air required for auxilary fuel
AQIRNU	Quantity of air required in tonne to burn one tonne of refuse plus the quantity of air required to burn auxilary fuel
CLI	Pay of a labor per hour working on incinerator
CDI	Depreciation cost of incinerator (civil work)
CDM	Depreciation cost of electrical and mechanical equipments

Appendix continued...

APPENDIX VI Continued.

CII	Interest cost on incinerator (civil work)
CIM	Interest cost on electrical and mechanical equipments
DDI	Average distance from a ward i to the incinerator
CQ(I)	Cost of refuse transportation per trip
CT(I)	Refuse transportation cost per tonne of refuse
BA	Cost of labour per tonne of refuse
PB	Power in KWH required by a blower
PC	Total power cost required by blowers
BB	Power cost per tonne of refuse
CQAF	Cost of auxilary fuel
CTT(I)	Cost of incineration of refuse Rs/tonne of refuse
TINC	Average temperature of the whole incinerator furnace
HINC	Heat lost through incinerator
HLINC	Heat lost through furnace walls
HAIR	Heat lost through air
HHUM	Heat lost through humidity in air
HLM	Heat lost through moisture present in refuse
HASH	Heat lost through inert material present in refuse

Appendix continued...

APPENDIX VI Continued.

HGAS	Heat lost through combustible material present in refuse
FR	Quantity of auxilary fuel required
COA	Total cost of auxilary fuel
FRATE	Rate of auxilary fuel feeding in incinerator during unsteady-state burning

APPENDIX VII

COMPUTER PROGRAM DEVELOPED FOR THE COMPUTATION OF COST OF TRANSPORTATION OF REFUSE AND COST OF INCINERATION OF REFUSE.

(DATA USED IN THIS PROGRAM ARE FOR 50 TONNES/DAY INCINERATOR CAPACITY)

```
$IBJOB
$IBFTC MAIN
      DIMENSION D(200),C(200),X(200),G(200),COST(200),Q(200),CQ(200),
     1 CTT(200),DD(200),CT(200)
      REAL I1,I2,LV,MU,IR,MC,MOS,LAMDA,M1,M2,MI,NI,NL,K
      N=30
      N2=2*N
      N4=4*N
      F1(C,FC)=C/FC
      F2(CM,MC)=CM/MC
      F3(VM,RN)=VM/RN
      F4(I1,I2,LV)=(I1-I2)/LV
      F5(LV,RN)=LV/RN
      F6(MU,I1,IR,RN)-(MU+1.)/(2.*MU)*I1*IR/RN
      F7(A,B,C,D,E)=A+B+C+D+E
      F8(X,Y)=X/Y
      F9(X,Y,Z)=X/(X*Y)
      F10(A,B,C,D,E,G,H,P,Q)=A*B+(C+D*E)*(A/G+H/(E*P)+H/(E*Q))
      READ400,CI,FC,CM,MC,VM,RN,I1,I2,LV,PD,WHM,PL,NL,RL,RU,RV,SP,RHO
      READ400,(G(I),I=1,N2)
      READ400,(D(I),I=1,N2)
      READ400,(DD(I),I=1,N4))
 400  FORMAT (8F10.2)
      CF=F1(CI,FC)
      CMO=F2(CM,MC)
      CMV=F3(VM,RN)
      CDV=F4(I1,I2,LV)
      MU=F5(LV,RN)
      CIV=F6(MU,I1,IR,RN)
      CO=F7(CF,CMO,CMV,CDV,CIV)
      CD=F8(PD,WHM)
      CL=F8(PL,WHM)
      ANL=NL
      TL=F9(RV,ANL,RL)
      TU=F9(RV,ANL,RU)
      DO 100I=1,N2
      DI=D(I)
      C(I)=F10(DI,CO,CD,CL,ANL,SP,RV,RL,RU)
      GT=G(I)/RHO
      X(I)=GT/RV
 100  CONTINUE
 200  CONTINUE
```

```
      DO 300 I=1,N2
      COST(I)=C(I)*X(I)
300   CONTINUE
      PRINT420,(I,C(I),I=1,N2)
      PRINT440,(I,X(I),I=1,N2)
C     PRINT430,(I,CQ(I),I=1,N4)
      PRINT450,(I,COST(I),I=1,N2)
420   FORMAT(5X,*REFUSE TRANSPORTATION COST FROM WARD I*,/5(I5,3X,
     *F10.2))
430   FORMAT(5X,*REFUSE TRANSPORTATION COST FROM WARD I TO THE INCINE
     *RATOR*/5(I5,3X,F10.2))
450   FORMAT(5X,*TOTAL COST*/5(I5,3X,F10.2))
440   FORMAT(5X,*NUMBER OF TRIPS FROM WARD I PER WEEK*/5(I5,3X,F10.2))
C
C
      Q1=135000.
      Q2=2700.
      NI=10.
      MI=10.
      M1=60000.
      M2=3000.
      HP=10.
      HR=2800000.
      QR=2.0
      HW=7200.
      CMI=2700.
      CMM=3000.
      QI=1.0
      PLI=150.
      WHM=240.
      AQ=0.852
      QAB=4.425
      CP=0.10
      TF=800.
      TO=30.
      CAF=500.
      FINERT=.3
      COMBUS=.4
      CPI=190.
      HRPT=1400000.
      HF=10750000.
      CPA=240.
      CV=1000.
      CW=1000.
      LAMDA=540000.
      K=0.02478
      ETA=0.01736
      W=0.35
      A=48.
      MOS=0.3
```

```
      QM=0.3
      ND=0.0
      TC=2.8
      IR=0.07
      WINC=55.
      CPINC=200.
C
C     CALCULATION FOR INCINERATOR 50 TONNE/DAY
C     QUANTITY OF AUXILARY FUEL AT STEADYSTATE BURNING
C     QAIR IS THE QUANTITY OF AIR REQUIRED IN TONNE TO BURN ONE TONNE OF
C     REFUSE
C     QF IS THE QUANTITY OF FUEL REQUIRED IN TONNE TO BURN ONE TONNE OF
C     REFUSE
      QAIR=HRPT*AQ/252000.
      AA=QAIR*CPA*(TF-TO)*QR
      AB=QAIR*CV*ETA*(TF-TO)*QR
      AC=QR*FINERT*CPI*(TF-TO)
      AD=QR*(QM*(CQ*(100.-TO)*LAMDA+(TF-100.)*CV))
      HTC=K/W
      AE=HTC*A*(TF-TO)
      AF=QR*HRPT
      AG=AR*COMBUS*CPA*(TF-TO)
      QF1=(AA+AB+AC+AD+AE+AG-AF)/(HF*QR)
      QAFUEL=HF*.0033*QF/2520.
      QAIRNU=QAIR+QAFUEL
      AA=QAIRNU*CPA*(TF-TO)*QR
      QF=(AA+AB+AC+AD+AE+AG-AF)/(HF*QR)
      PRINT550,QAIR,AA,AB,AC,AD,AE,AF,AG,QF1,QF
550   FORMAT(/1X,*QAIR=*E15.6,5X,*AA=*E15.6,5X,*AB=*E15.6,5X,*AC=*E15.6/
     11X,*AD=*E15.6,5X,*AE=*E15.6,5X,*AF=*E15.6,5X,*AG=*E15.6/
     25X,*QF1=*E15.6,5X,*QF=*E15.6)
C     COST OF LABORER RS/HOUR
      CLI=PLI/WHM
C     COST OF DEPRECIATION, MAINTENANCE AND INTEREST
      CDI=(Q1-Q2)/NI
      CDM=(M1-M2)/MI
      CII=Q1*IR*(NI+1.)/(2.*NI)
      CIM=M1*IR*(MI+1.)/(2.*MI)
      CTO=(CDI+CDM+CII+CIM+CMI+CMM)/(QR*HW)
C     CALCULATION OF CQ(I)
      CO=F7(CF,CMO,CMV,CDV,CIV)
      DO 700 I =1,N4
      DDI=DD(I)
      CQ(I)=F10(DDI,CO,CD,CL,ANL,SP,RV,RL,RU)
      CT(I)=CQ(I)/TC
700   CONTINUE
C     COST OF TRANSPORTATION OF REFUSE FROM WARD I TO THE INCINERATOR
C     RS/TONNE OF REFUSE INCINERATED
      CLI=PLI/WHM
      BA=CLI/QI
```

```
      PB=HP*0.746
      PC=((HR*AQ/252000.+QAFUEL)-(QR*FLOAT(ND)))*PB*CP/QAB
      BB=PC/QR
      CF=F1(CI,FC)
      CQAF=CAF*QF1
      DO 800 I=1,N4
      CTT(I)=BA+BB+CT(I)+CAF*QF+CTO
800   CONTINUE
      PRINT 401,QF,BA,BB,CTO
401   FORMAT (/,5X,*QF=*,F10.3,*BA=*,F10.3,*BB=*,F10.3,*CTO=*,F10.3,/)
      PRINT 408
      PRINT 410,(I,CT(I),CTT(I),I=1,N4)
408   FORMAT (5X,*WARD                CT                    TOTALCOST*,/)
410   FORMAT(5X,I6,2F15.3)
C     QUANTITY OF AUXILARY FUEL AT UNSTEADYSTATE INITIAL BURNING
C     CALCULATION FOR FR
C     TINC=AVERAGE TEMPERATURE OF THE WHOLE INCINERATOR, TINC IS
C     ASSUMED AS (50P.C. OF (TF-TO)+TO)
      DO 750 I=1,4
      T=I
      TIME=T*.5
      TINC=(TF-TO)*0.5+TO
      HINC=WINC+CPINC*(TINC-TO)
      HLINC=HTC*A*((TO+TF)(2.-TO)*TIME
      HAIR=QAIR*CPA*(TF-TO)*QR*TIME
      HHUM=QAIR*CV*ETA*(TF-TO)*QR*TIME
      HLM=AD*TIME
      HASH=QR*FINERT*CPI*(TF-TO)*TIME
      HGAS=QR*COMBUS*CPA*(TF-TO)*TIME
      FR=(HINC+HLINC+HAIR+HHUM+HLM+HASH+HGAS)/HF
      QAFUEL=HF*.0033*FR/2520.
      QAIRNU=QAIR+QAFUEL
      HAIR=QAIRNU*CPA*(TF-TO)*QR*TIME
      FR=(HINC+HLINC+HAIR+HHUM+HLM+HASH+HGAS)/HF
      FRATE=FR/TIME
      COA=FR*CAF
      PRINT500,HINC,HLINC,HAIR,HHUM,HLM,HASH,HGAS
500   FORMAT(/5X,*HINC=*E15.6,5X,*HLINC=*E15.6,5X,*HAIR=*E15.6/5X,
     1*HHUM=*E15.6,5X,*HLM=*E15.6,5X,*HASH=*E15.6,5X,*HGAS=*E15.6)
      PRINT 460,FR,COA,FRATE
460   FORMAT(/5X,*FR=*E15.6,5X,*COA=*E15.6,5X,*FRATE=*E15.6)
      PRINT 1800,CTO,BA,BB,QF,CQAF
1800  FORMAT(/1X,*CTO=*E15.6,5X,*BA=*E15.6,5X,*BB=*E15.6,5X,*QF=*E15.6,
     15X,*CQAF=*E15.6/)
750   CONTINUE
      STOP
      END
$ENTRY
```